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Evaluation of Damage Control Tactics and Equipment - Phase II, Baseline Tests

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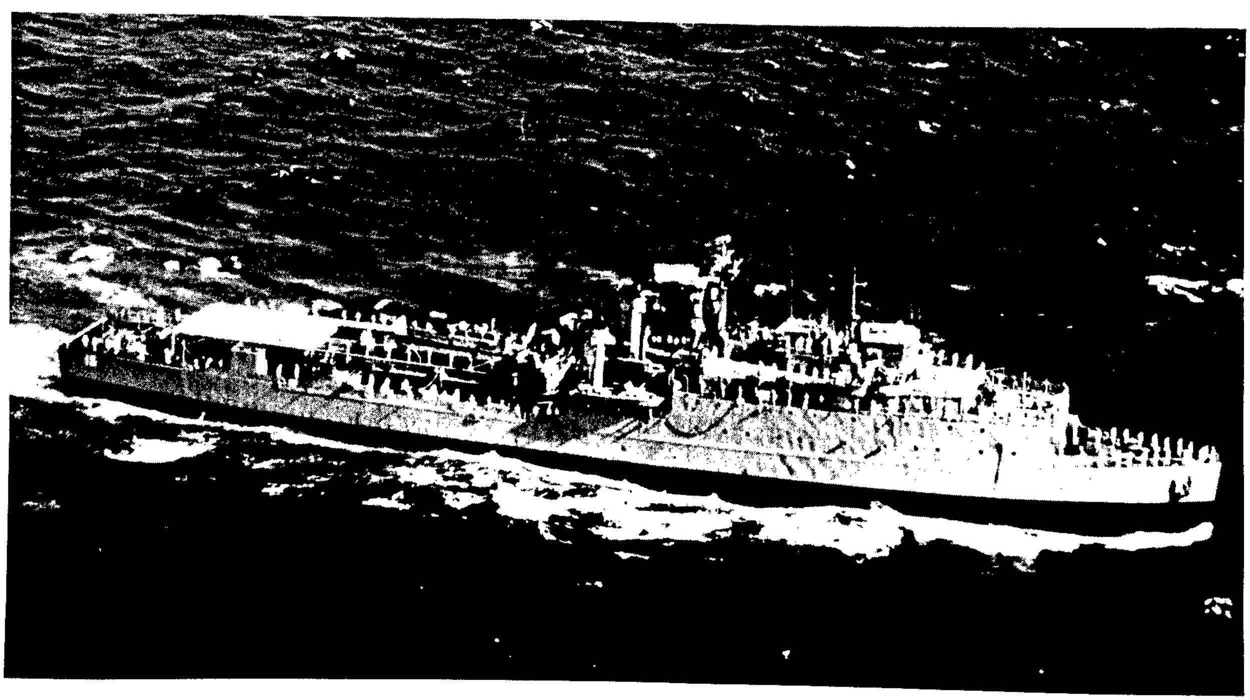

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13. ABSTRACT *(Maximum 200 words)*

This report summarizes results from the second baseline series of damage control tests involving pipe patching, shoring, dewatering, and hull repair.

In pipe patching, the EWARP patch was more effective on isolated (non-pressurized) systems than the soft patch and Fleetpak kit. The Fleetpak kit was ineffective on all of the isolated systems and required more material than recommended.

The combination K-shore was constructed in less time than any of the other shoring methods. The wooden K-shore required significantly more time to construct than the combination K-shore. There were no significant differences in the times required to construct wooden and combination H-shores.

There were significant differences in the rigging times for the various pieces of dewatering equipment. There were also substantial differences in the total time required to begin dewatering and the dewatering rate.

None of the hull repair methods evaluated were consistently effective in repairing actively flowing hull ruptures. The plate patch was an effective repair method for hull ruptures when installed without water flowing through the rupture.

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EVALUATION OF DAMAGE CONTROL TACTICS AND EQUIPMENT: PHASE II, BASELINE TESTS

1.0 INTRODUCTION

Research and development to address damage control tactics, techniques, and procedures was initiated by the Naval Sea Systems Command (NAVSEA) and the Naval Research Laboratory (NRL). This research was aimed at improving the following areas: integrated damage control tactics and techniques, equipment, and secondary damage modeling.

The test series discussed in this report is the second of two test series intended to provide baseline data from which new tactics and equipment can be compared. The results of the first test series are reported in reference (a). The repair activities evaluated in these tests included pipe patching, shoring, dewatering, and hull repair. All of the equipment used in these tests are currently available to the repair team.

The port wing wall of the ex-USS SHADWELL, NRL's full-scale fire research platform (reference. (b)), was used for this test series. The port wing wall has been modified to simulate a single flooded compartment. In the planned FY 96 test series, a second flooded compartment will be added to evaluate progressive flooding threats. These modifications are discussed in reference (c).

2.0 OBJECTIVE

The primary objective of the FY 95 testing is to develop the data necessary in quantifying individual functional damage control tactics and techniques, including equipment setup times, in uncontrolled flooding scenarios. These data can then be used to analyze damage control tactics and procedures and repair party manning issues. New personnel protective equipment can also be evaluated.

In the initial test series, discussed in reference (a), shoring, dewatering, pipe patching, and hull repair techniques were evaluated. The shoring tests examined the use of wood and wood/metal combinations in constructing I and K shores. The dewatering tests included three pumps: (1) P-100, (2) P-250, and (3) electrical submersible pump. The dewatering tests were performed with a 3.0 m (10 ft) lift. The pipe patching tests evaluated the repair of pressurized lines using the pipe wrench with the banding kit and the jubilee patch. The pipe patching tests were performed using a variety of pipe sizes and pipe ruptures. The hull repair tests focused on the use of the bucket patch and the plugs and wedges approach to repairing explosion and implosion ruptures. The bucket batch was used in conjunction with "J" and "T" bolts.

In the July 1995 test series, shoring, dewatering, pipe patching, and hull repair techniques were again evaluated. The shoring tests examined the use of wood and wood/metal combinations in constructing H and K shores. The dewatering tests included two pumps: (1) P-100 and (2) P-250. The dewatering evaluation also included the use of an eductor connected to the firemain. These tests were performed with a 6.1 m (20 ft) lift. The pipe patching tests evaluated the repair of isolated (non-pressurized) lines using

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the soft patch, Fleetpak, and the Emergency Water Activated Repair Patch (EWARP) repairs. These tests were performed on simulated Chill Water and Firemain lines. The hull repair tests focused on the use of the bucket and plate patches reinforced with wood and metal "I" shoring to repair explosion and implosion ruptures.

3.0 DAMAGE CONTROL EQUIPMENT ALLOWANCES

The shoring equipment used was typical of the equipment currently available in a shipboard repair station. Two types of shores were evaluated: (1) all wood and (2) wood and steel. The steel shoring was used in conjunction with wood shoring to demonstrate the ease of erecting and time required to position the combination shore. The pipe patching equipment used in this test series included onboard allowances. The onboard allowances included: (1) the soft patch, (2) the Fleetpak patch, and (3) the EWARP patch.

A total of seven different dewatering equipment configurations were evaluated during this test series, including: (1) P-250 with a foot valve, (2) P-250 with a 38 mm (1.5 in.) eductor, (3) P-250 with a 64 mm (2.5 in.) eductor, (4) P-100 with a foot valve, (5) P-100 with a 38 mm (1.5 in.) eductor, (6) 38 mm (1.5 in.) eductor off of the firemain, and (7) 64 mm (2.5 in.) eductor off of the firemain.

Hull repairs were accomplished using equipment currently available in the repair locker. Wood and metal shoring was used in conjunction with the bucket and plate patches. All of the damage control equipment evaluated in this test series is described in reference (d).

4.0 TEST COMPARTMENTS

The port wing wall of the ex-USS SHADWELL, shown in Fig. 1, was used for the Damage Control testing. The areas between frames 88 and 95 on the first, second, and third decks and the area between frames 81 and 88 of the second deck were the primary test areas. These areas were referred to as the Fan Room, Upper Wet Compartment, Lower Wet Compartment, and Ward Room, respectively. The layouts for these compartments are shown in Figs. 2-5. The area between frames 90 and 93 in the well deck was also used. This area was referred to as the Well Deck.

The Fan Room, shown in Fig. 2, provided access to the Upper Wet Compartment via a watertight hatch (WITH 1-89-2). The hull repair and dewatering teams entered the Upper Wet Compartment through this hatch. The dewatering teams used a scuttle (QAS 1-93-2), located inboard of the Fan Room at weather, to lower their equipment into the Upper Wet Compartment. The hull repair and dewatering teams were staged immediately aft of the Fan Room prior to test initiation.

The Upper Wet Compartment, shown in Fig. 3, was used primarily for hull and pipe repair tests. The dewatering team used a scuttle (QAS 2-94-2) to lower their equipment into the Lower Wet Compartment. The chill water line was used in the pipe patching tests. The chill water line consisted of copper/nickel (90/10) pipe with an outside diameter of 60.3 mm (2.4 in.) and a wall thickness of 2.1 mm (0.08 in.). This line entered the compartment along the inboard bulkhead at frame 88 and ran aft to frame 90. At frame 90, the chill water turned and ran to the outboard bulkhead, where the line terminated. The chill water line was supplied by a 1325 Lpm (350 gpm) portable electric pump, connected to the chill water line forward of frame 88 in the Ward Room. A pressure reducing valve maintained a static pressure of approximately 3.8 bar (55 psi) in the chill water line.

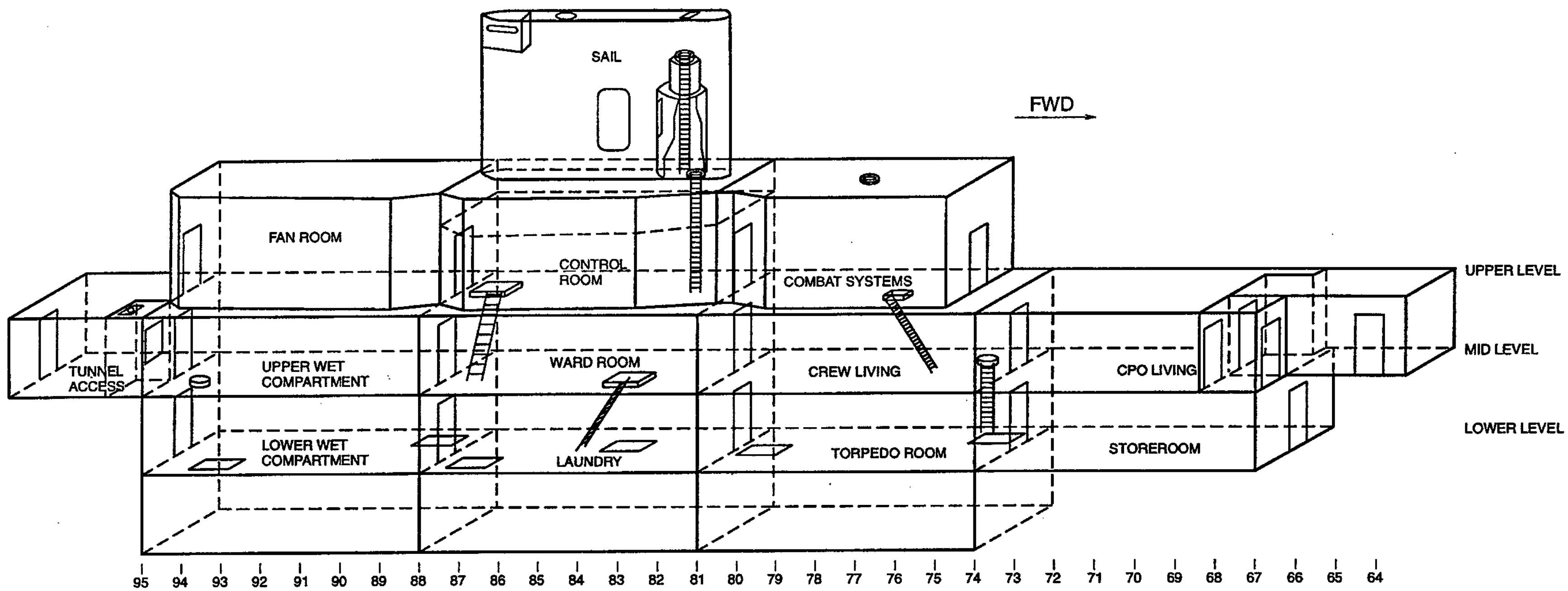


Fig. 1 – Port wing wall test area

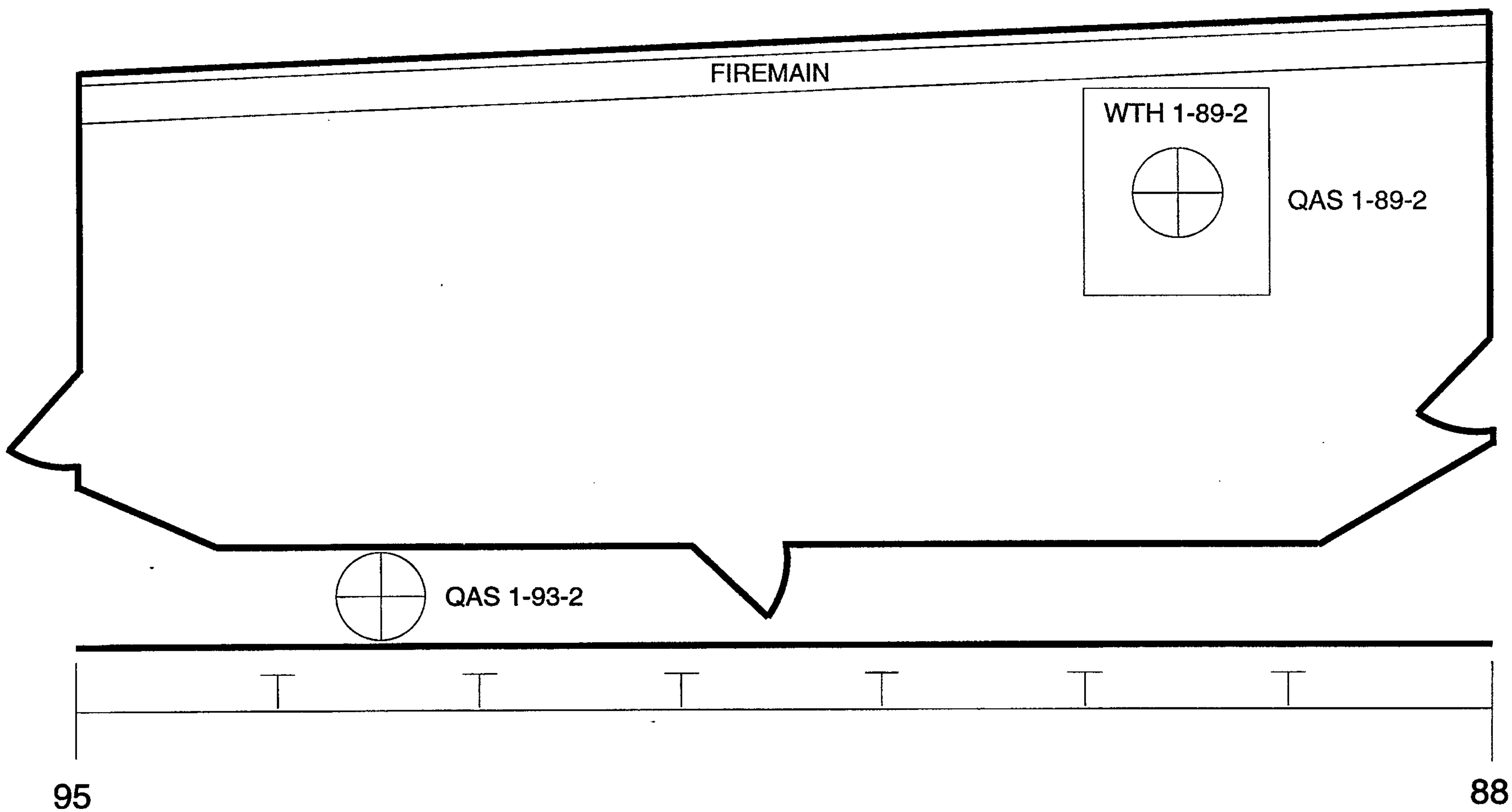


Fig. 2 – Fan room layout

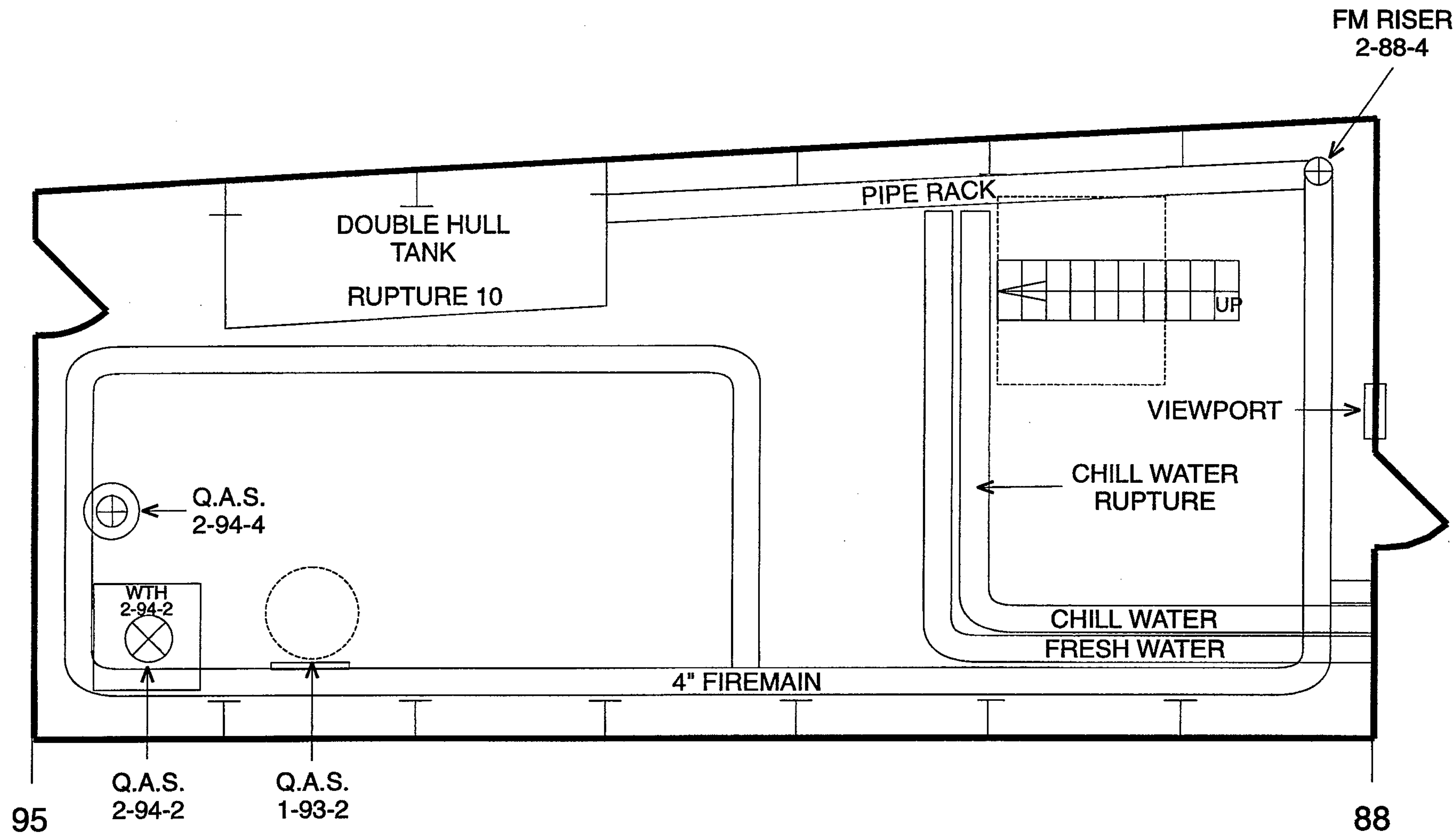


Fig. 3 – Upper wet compartment layout

The Ward Room, shown in Fig. 4, was used primarily for the shoring tests. The pipe patching team was staged in the Ward Room prior to the chill water pipe repair tests. The team entered the Upper Wet Compartment through a watertight door (WTD 2-88-2). The shoring team was staged on the steel platform, located inboard of the Wardroom. All of the cutting operations were performed on this platform. Two watertight doors (WTD 2-82-2 and WTD 2-86-2) provided access to the Wardroom from the platform.

The Lower Wet Compartment, shown in Fig. 5, was used only for the dewatering tests during this test series. In future test series, this compartment will be used in cascading flooding scenarios.

The Well Deck was used for the pipe patching tests. The pipe rig, shown in Fig. 6, was located in this area. The pipe rig consisted of several pipe sizes and ruptures. The pipe used during this test series consisted of copper/nickel (90/10) pipe with an outside diameter of 89 mm (3.5 in.) and a wall thickness of 2.4 mm (0.1 in.). The pipe rig was supplied by the ship's firemain via 38 mm (1.5 in.) fire hose. The firemain was supplied by the ship's primary fire pump, a 3785 Lpm (1000 gpm) pump. This pump maintained a static pressure of approximately 8.3 bar (120 psi) at the pipe rig.

5.0 DAMAGE

Two separate pipe ruptures were used during this test series. The first rupture, shown in Fig. 7, was located in the chill water line in the Upper Wet Compartment. The chill water rupture was a split seam rupture, measuring 152 mm x 13 mm (6 in. x 0.5 in.), located at 2-90-2. A pressure reducing valve maintained a static pressure of 3.8 bar (55 psi) in the chill water line. This rupture flowed approximately 59 Lpm (13 gpm) and had a nominal residual pressure of zero. The second pipe rupture was located on the pipe rig in the Well Deck. This pipe rupture measured 102 mm (4 in.) x 38 mm (1.5 in.) and simulated simple compound damage with jagged edges in the ship's firemain. This rupture flowed 340 Lpm (90 gpm) with a residual pressure of 6.1 bar (89 psi). It is important to point out that water to the pipe ruptures was secured prior to the initiation of any repair activities.

The shoring team was responsible for constructing two types of shores (H and K). Both types of shores were used to reinforce a weakened bulkhead at 2-85-2 in the Wardroom.

All of the dewatering tests used the same scenario. The Lower Wet Compartment was filled with water to an initial depth of approximately 0.6 m (2 ft). All of the dewatering equipment was located aft of the Fan Room. This resulted in a 6.1 m (20 ft) lift.

Two types of hull ruptures, implosion and explosion, were used during this test series. Both of these ruptures, shown in Fig. 8, were supplied by water contained in the double hull and pilot house tanks. Both hull ruptures were located in the Upper Wet Compartment as shown in Figure 3. The pilot house tank supplied the double hull tank, which in turn supplied the ruptures. In an attempt to maintain a significant head pressure, the pilot house tank was continuously supplied by the ship firemain during the test. The explosion rupture consisted of a single circular hole with a diameter of approximately 178 mm (7 in.). With the firemain supply secured this rupture initially flowed 11, 240 Lpm (2969 gpm). After three minutes of unobstructed flow, the rupture flowed 5190 Lpm (1371 gpm). After four minutes of unobstructed flow, the water in the Upper Wet Compartment was at equilibrium with the water in the double hull tank. The implosion rupture consisted of a single circular hole with a diameter of

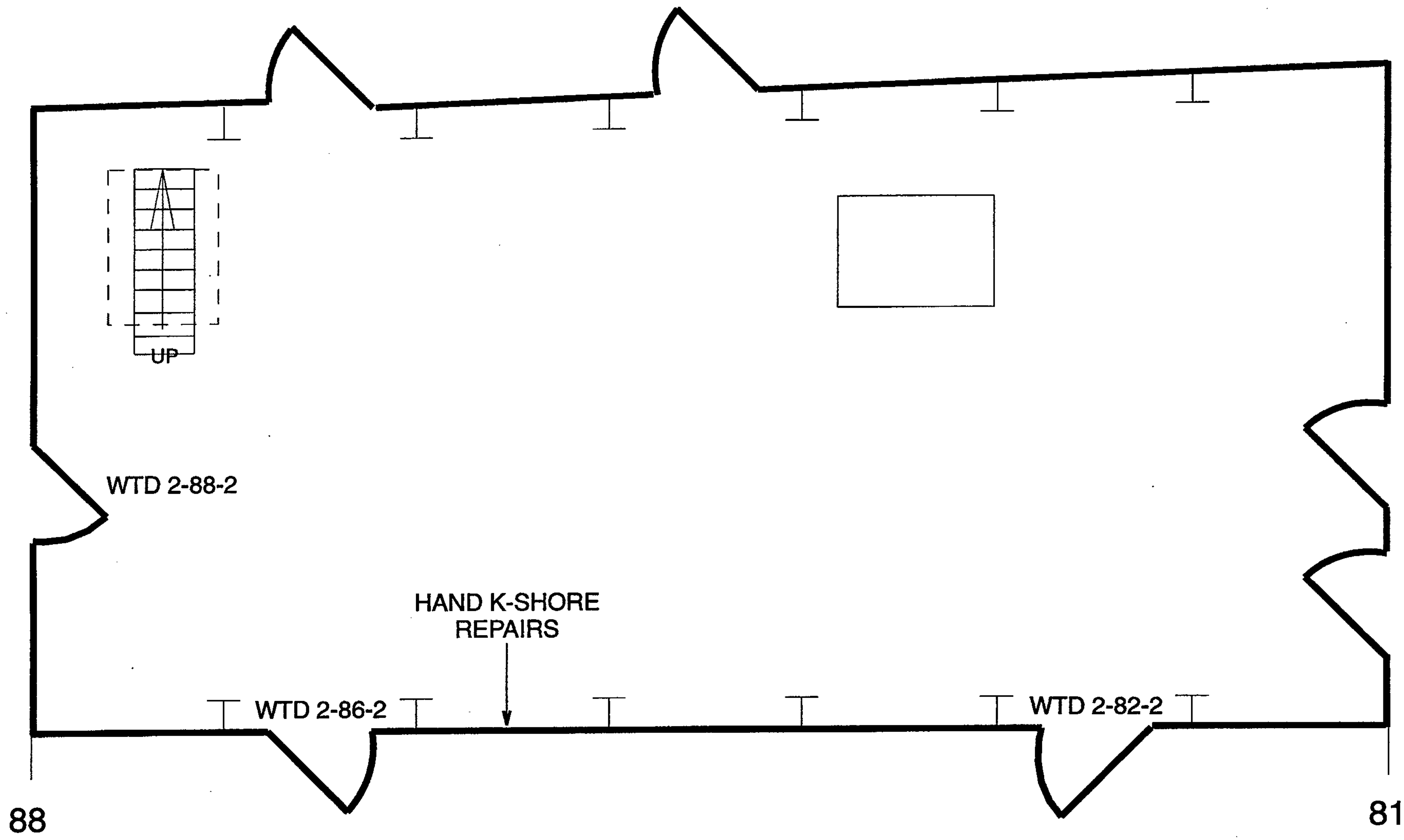


Fig. 4 – Wardroom layout

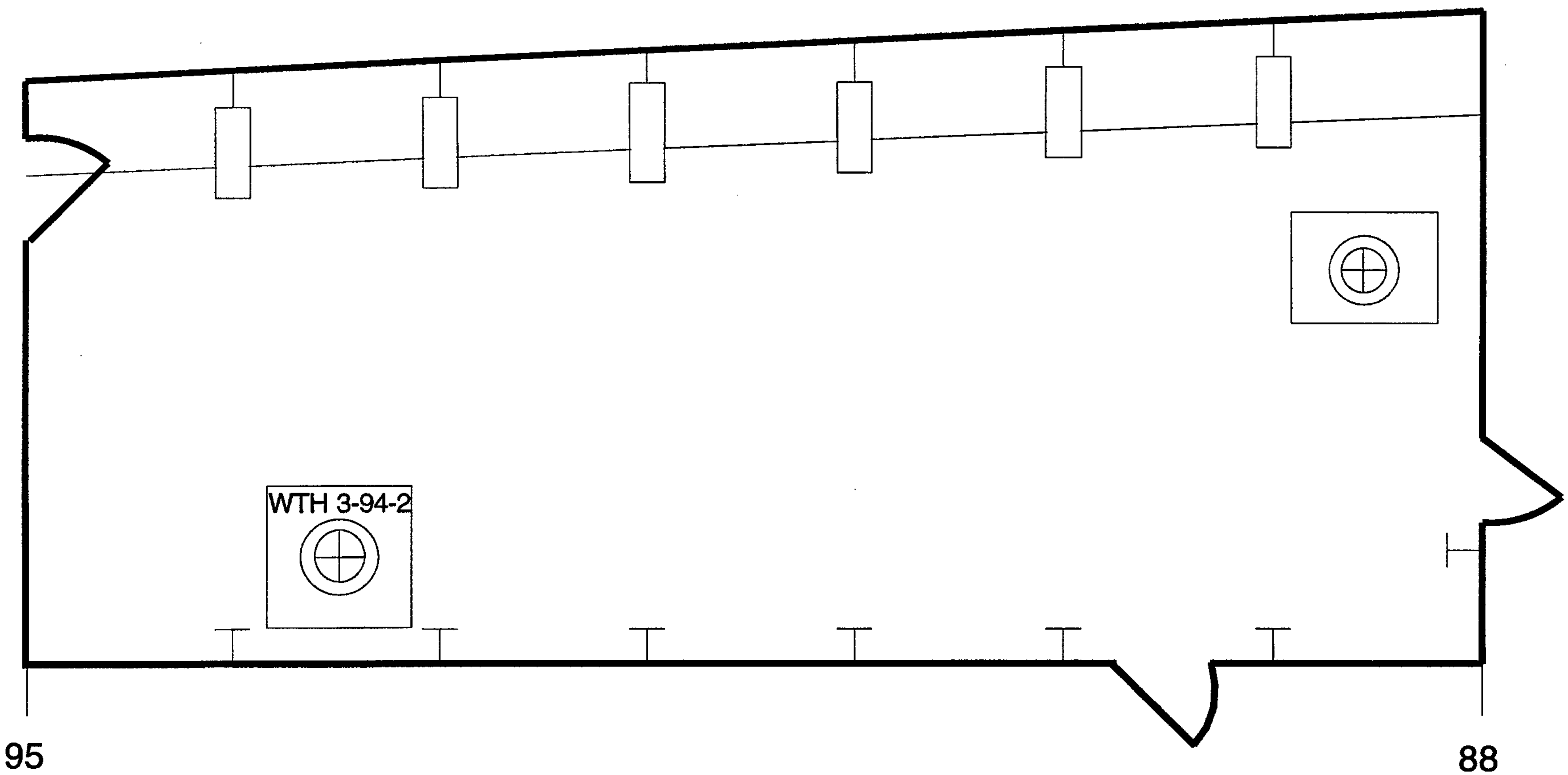


Fig. 5 – Lower wet compartment layout

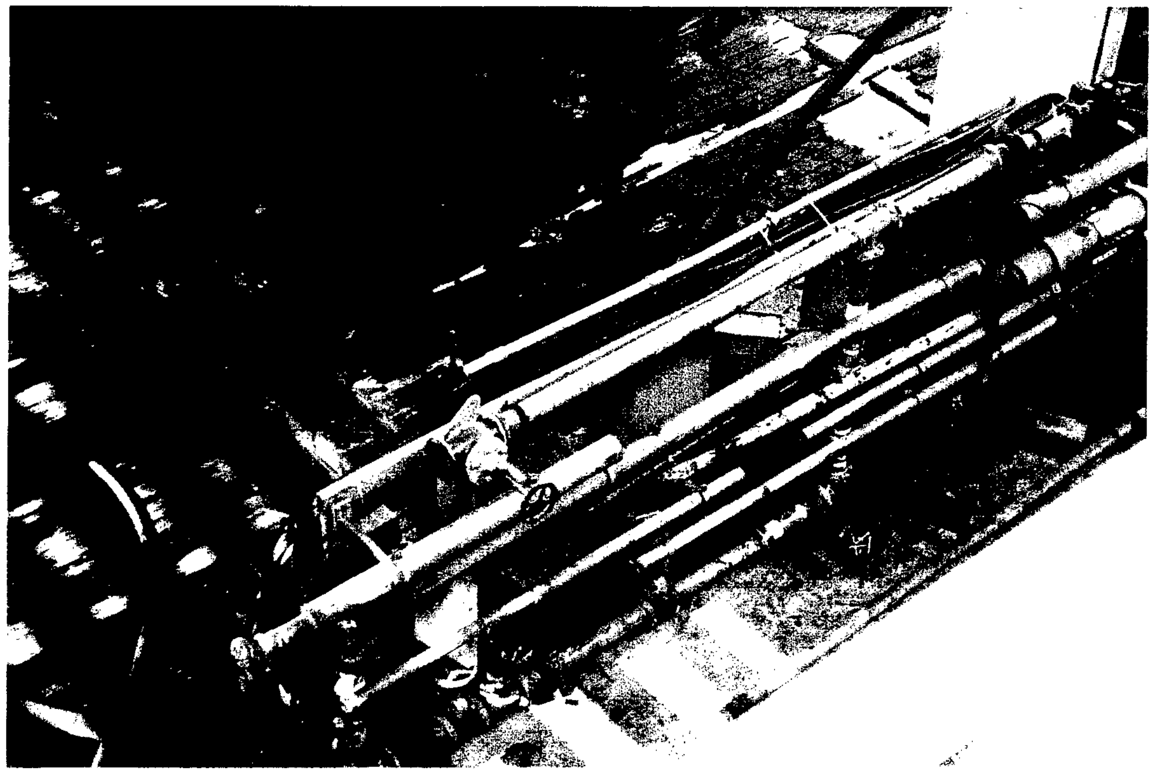


Fig. 6 – Pipe rig located in well deck

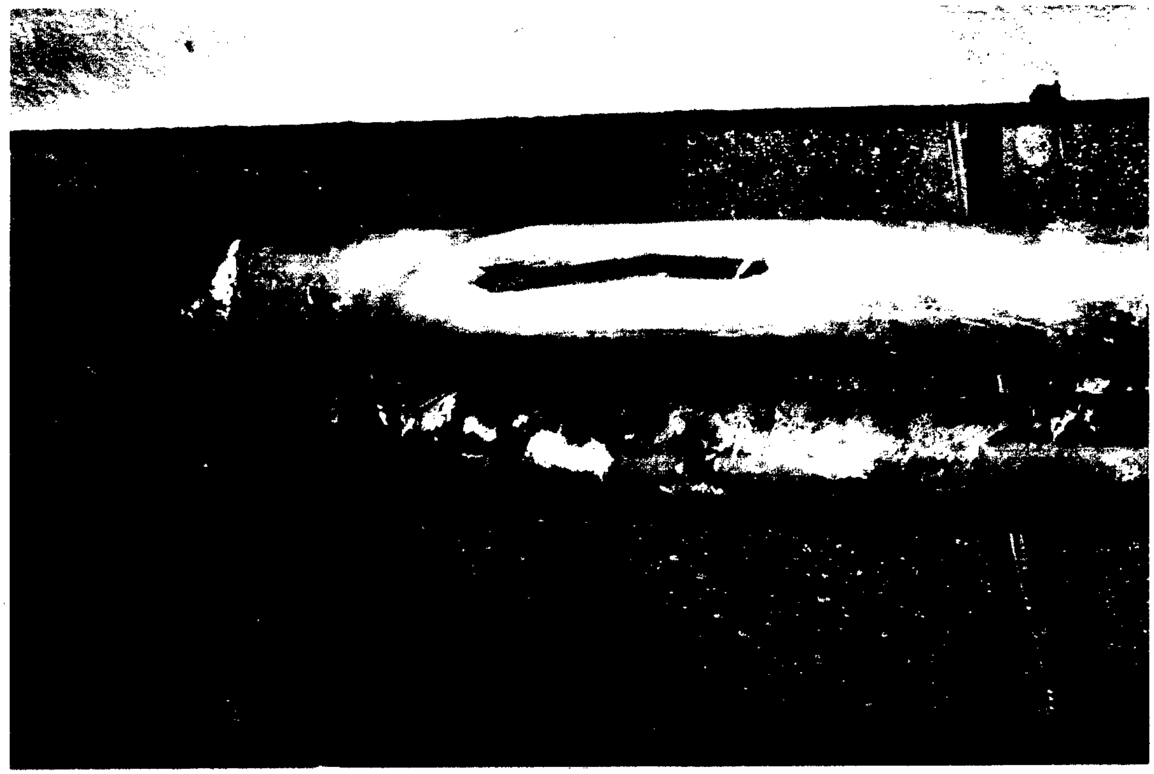
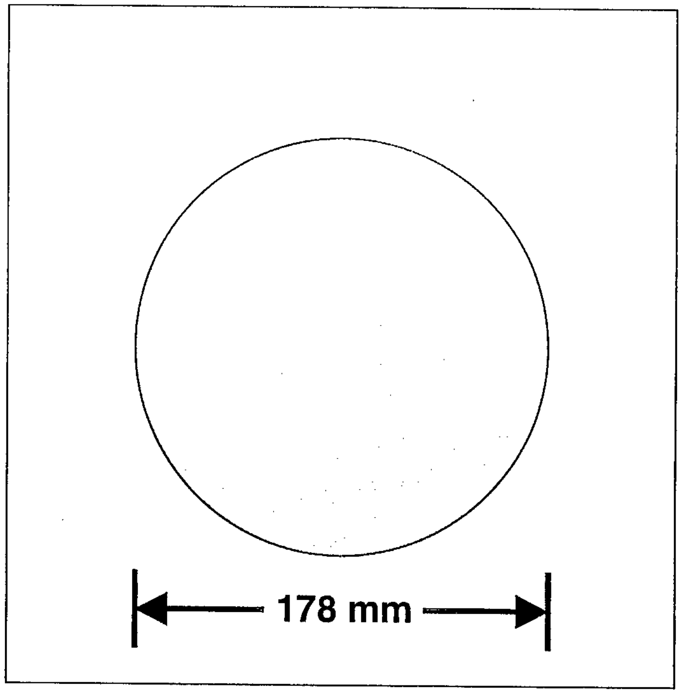


Fig. 7 – Chill water pipe rupture



Explosion

Implosion

Fig. 8 – Implosion and explosion hull ruptures

approximately 100 mm (4 in.). This rupture initially flowed 4876 Lpm (1288 gpm) with the firemain supply secured. After six minutes of unobstructed flow, the rupture flowed 4281 Lpm (1131 gpm). The initial head pressure for both scenarios was approximately 6 m (20 ft).

6.0 INSTRUMENTATION

The test area was instrumented to provide pressure, flow rate, liquid level, and temperature measurements. The instrumentation layout is shown in the figures contained in Appendix A. In addition, a complete description of all of the instrumentation, including audio and video, is provided in the channel listing contained in Appendix B.

Temperature was measured with two thermocouple strings. The first thermocouple string, located at 2-94-2, consisted of seven type-K, inconel-sheathed thermocouples. The thermocouples were positioned at 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, and 2.1 m (1.0, 2.0, 2.9, 3.9, 4.9, 5.8, and 6.8 ft) above the deck. The second thermocouple string was located at 3-93-2 and consisted of five type-K, inconel-sheathed thermocouples. These thermocouples were positioned at 0.5, 1.0, 1.5, 2.0, and 2.5 m (1.6, 3.2, 4.9, 6.5, 8.1 ft) above the deck. These provided ambient air temperature measurements and the capability to measure water temperature in the proposed cold water tests.

Flow rate was measured to determine the effectiveness of the pipe repair activities. The chill water flow rate was measured using an Omega turbine flow meter with a range of 0 to 852 Lpm (0 to 225 gpm). The turbine flow meter was installed at 2-88-2 in the chill water line. The flow rate through the pipe rig was measured using a Controlotron ultrasonic flowmeter. The flow meter was located on a section of the pipe rig piping that remained full when water was secured to the pipe rupture.

Pressure measurements were also made to determine the effectiveness of the pipe repair activities. The chill water pressure was measured using a Setra Model 207 pressure transducer with a range of 0 to 17.2 bar (0 to 250 psi). The chill water pressure measurement was made at the same location as the flow rate, 2-88-2. The pipe rig pressure was also measured using a Setra Model 207 pressure transducer with a range of 0 to 17.2 bar (0 to 250 psi). This measurement was made at the point where the firemain was connected to the pipe rig.

Water level measurements were made using fiberoptic pressure sensors. These measurements were recorded by the Damage Control Flooding Sensor Computer, developed and installed by NSWC Annapolis. The water levels in the pilot house, storage tank, Upper Wet Compartment, and the Lower Wet Compartment were all recorded.

Each repair team was paired with an on-scene observer. The on-scene observer recorded the actual repair time as well as qualitative data. The observers made initial determinations of the effectiveness of the repair activity. This effectiveness was based on the effect of the repair on the damage, the repair technique, and the time to complete the repair activity. The on-scene observers commented on equipment and items used and not used in each of the repair kits. They also made observations related to manpower requirements.

7.0 EXPERIMENTAL DESIGN

The test matrix was developed to allow a reliable statistical analysis of the test data (reference (e)). The statistical design was used to determine the effects of each test variable on the effectiveness of the repair and the effects of improved performance as a function of test repetition (i.e. "learning curve effects"). The matrix was designed to eliminate fatigue as a factor by providing adequate rest time for each of the repair teams between tests. Due to on-site considerations, the actual test schedule deviated slightly from the proposed schedule. Tests were combined to maximize the use of the test period. It is important to note that the activities of one test did not interfere with those of another and, therefore, would not have any effect on any subsequent statistical analysis.

The tests were conducted July 19-26, 1995 aboard the ex-USS SHADWELL. Dewatering tests were conducted on each of the seven test days. Pipe patching tests were conducted on all but the last day of testing. Shoring tests were performed on the first three test days (July 19-21) and the hull repair tests were performed on the last four days of testing (July 22 and July 24-26). Each of the repair teams consisted of crew members from the USS BENFOLD.

7.1 Pipe Patching Repair Procedures

The pipe ruptures in the chill water line and in the pipe rig were repaired using soft patches, Fleetpak patches, and EWARP patches. Before beginning each repair, the system was pressurized, allowing water to flow through the pipe rupture, to determine the initial flow rate and the initial residual pressure in the water line. The repairs were then performed with the system isolated. After the repairs were completed, the system was pressurized to determine the final residual pressure and flow rate.

The soft patch, shown in Fig. 9, consisted of soft wooden wedges which were cut off flush to the pipe surface after being driven into the rupture. The pipe was then wrapped with packing material, sheet metal, and finally with marlin or wire.

Before applying the EWARP patch, shown in Fig. 10, the surface of the pipe around the rupture had to be scored with a file and cleaned to provide a satisfactory surface for resin adhesion. The roll of EWARP was immersed in water for 20 seconds. The EWARP was then centered over the leak and wrapped as shown in Fig. 10.

The Fleetpak kit consisted of resin, fiberglass tape, spatulas, gloves, carborundum paper, plastic release sheet, and instructions. Before applying the patch, the area to be patched was roughened. Abrasive paper was included in the kit for hand sanding. The white and black liquids contained in the pouch were thoroughly mixed. When the mixture was ready, the contents were squeezed onto a flat surface. Using a spatula, a priming layer of resin was applied to the repair area. The fiberglass tape was pressed into the resin before being wrapped around the pipe. The tape was then covered with additional resin. This process was repeated until there were at least two layers of laminate.

7.2 Shoring Repair Procedures

Both "H" and "K" shoring procedures were employed using both wooden shoring alone and a combination of wood and metal shoring. The shores were used to support a weakened bulkhead (2-85-2). The "H" shore is used when support must be distributed over a large area of a bulkhead and/or there is no suitable means of anchoring the bottom end of a strong back to a nearby structural member (i.e. in large

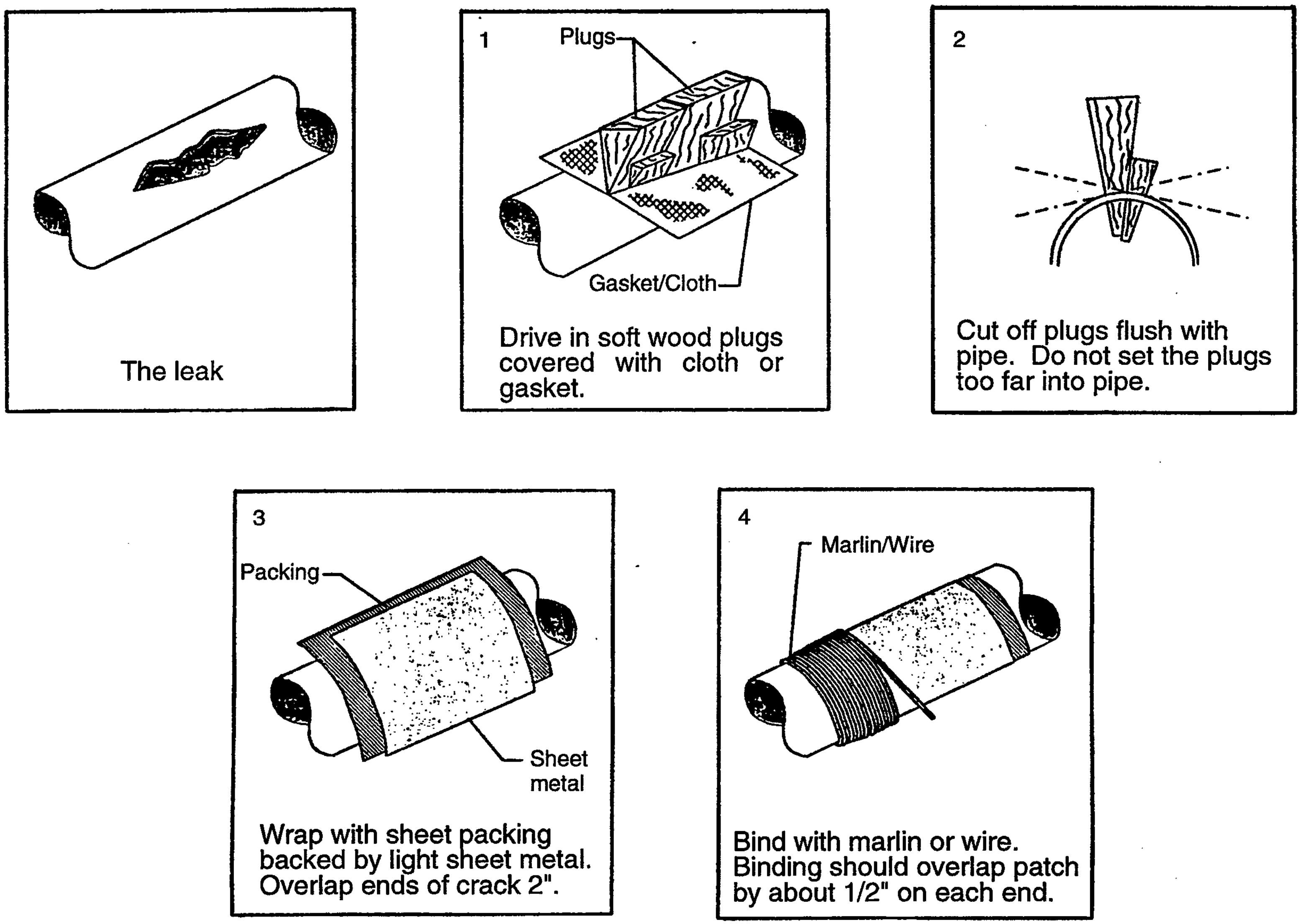


Fig. 9 – Soft patch on low-pressure pipe line, Ref. (d)

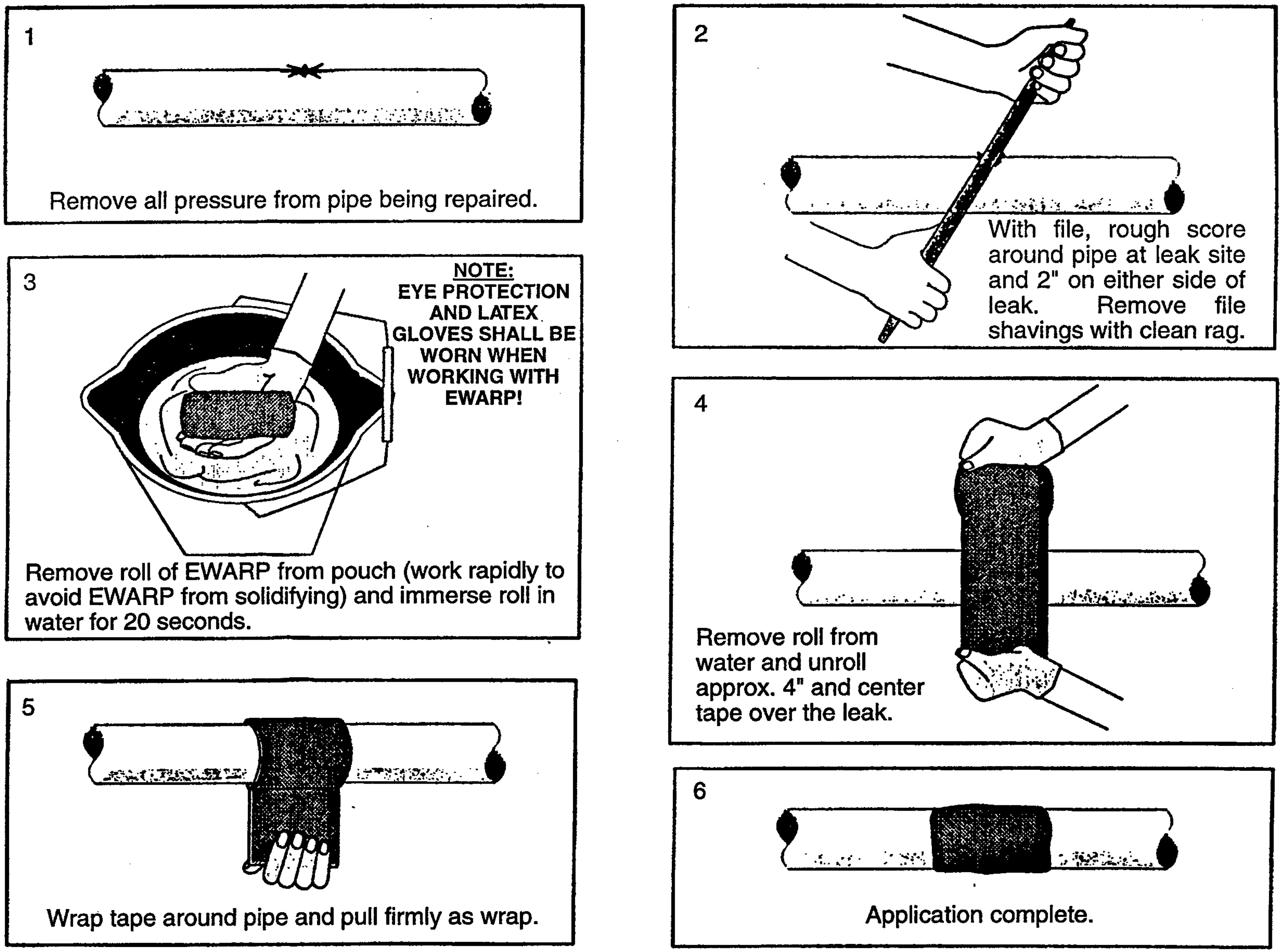


Fig. 10 – Emergency water activated repair patch (EWARP), Ref. (d)

compartments). Wooden "H" shores were constructed as shown in Fig. 11. The slanted strongback was cut to a length 1.1 times the distance from the overhead to the deck. Using backing plates (sholes) at the top and the bottom, the strongback was wedged into place. The next step was to measure and cut the horizontal and vertical bulkhead strongbacks. The horizontal strongbacks were evenly spaced over the height of the bulkhead. Wedges were prepared for use with each of the horizontal shores. The horizontal shores were installed starting with the lowest and working to the highest. Two wedges were used between the horizontal and vertical strongbacks to apply equal pressure on each shore. In the combination shore, these shores were replaced with metal shoring. In this case wedges were not necessary.

The wooden K-shore, shown in Fig. 12, was used to strengthen and support a weakened bulkhead. The first step in constructing this shore was to establish the upper and lower anchor points for the arms of the K-shoring. The lower anchor point for the shore foot was provided by a horizontal support (wood shoring) cut to extend to the closest intact structural member. The upper anchor point was provided by an existing transverse stiffener. The upper and lower legs were then cut to length, with allowance for the thickness of the strongback placed against the weakened bulkhead. The ends of the upper and lower legs were cut to obtuse angular points of approximately 90 degrees, such that the load bearing surfaces were parallel to the adjacent bearing surfaces of the deck, stiffeners, strongback, shores, etc. The entire K-shore was then tightened up using wedges as necessary between the shore legs and the strongback, the deck, and the overhead. Where required, lag bolts were used to fasten the wooden members in place.

The wood/metal combination K-shore is shown in Fig. 13. The anchor point for the upper and lower legs were established by cutting a piece of wooden shoring and then positioning it vertically with wedges. The lower horizontal support was placed on the deck between the vertical shore and the closest structural member, then tightened in place with wedges. The upper horizontal support was positioned between the vertical shore and the closest structural member, approximately 0.5 m (1.5 ft) from the overhead, then tightened in place with wedges. Two strongbacks were then positioned adjacent to each other and flush against the weakened bulkhead at the approximate midpoint between the deck and the overhead. Two telescoping metal shores were then positioned, with one between the lower end of the vertical wooden shore and the strongback and the other between the upper end of the vertical wooden shore and the strongback. After telescoping the shores, the self-aligning ends were lag bolted in place. The shores were then tightened with the adjustable screw jacks.

7.3 Dewatering Procedures

The dewatering tests were performed using the P-100 pump, P-250 pump and eductors supplied from the firemain. Dewatering of the Lower Wet Compartment was performed from the port wing wall on the main deck. Scuttles in the main and second decks (QAS 1-93-2 and QAS 2-94-2) were used to lower the dewatering equipment into the flooded compartment.

When personnel dewatered with the suction hose and foot valve, the P-250/P-100 pump and hoses were positioned on the weather deck. The suction hose and foot valve were lowered into the flooded compartment. This resulted in a lift of approximately 6.1 m (20 ft). The pump was rigged as shown in Fig. 14. For the P-250, the suction hose was primed, and then the pump was started. The P-100 pump is self priming. Since river water was being used for the dewatering tests, pumped water was discharged overboard.

When personnel dewatered with the 38 mm (1.5 in.) or 64 mm (2.5 in.) eductor, the pump was connected to the foot valve as described above, however, the pump discharge was connected via a fire

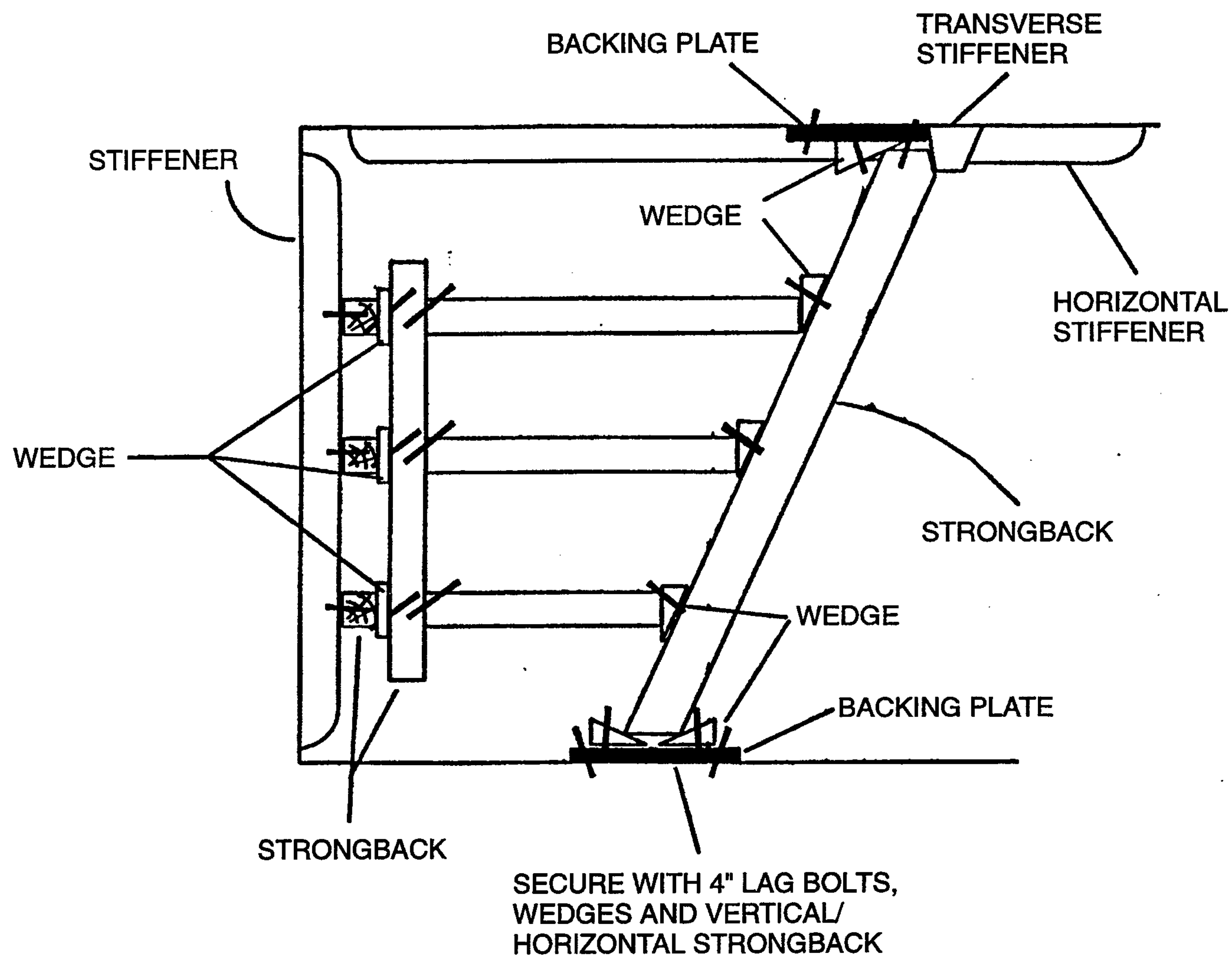


Fig. 11 – Wooden H-type shoring, Ref. (d)

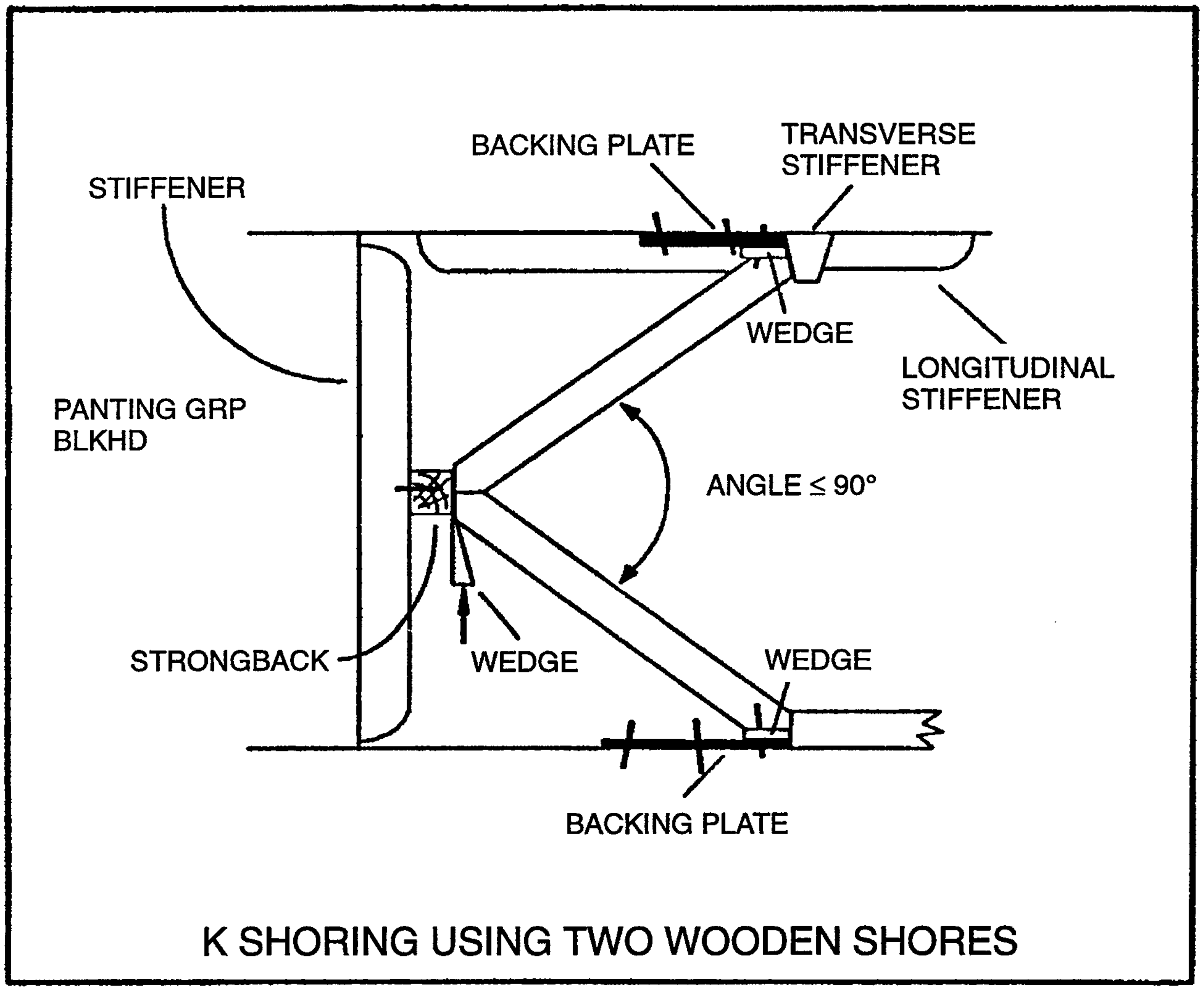
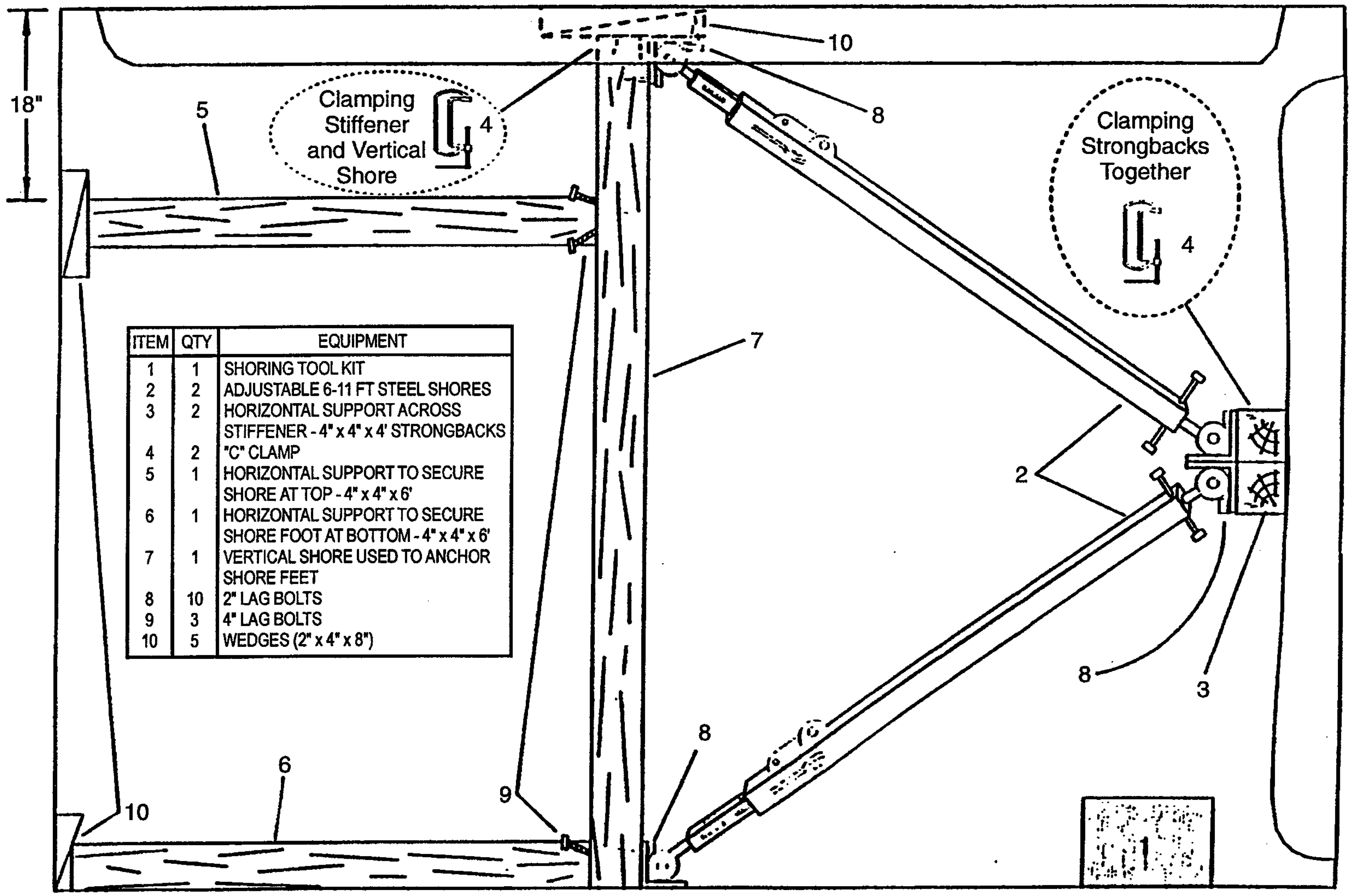


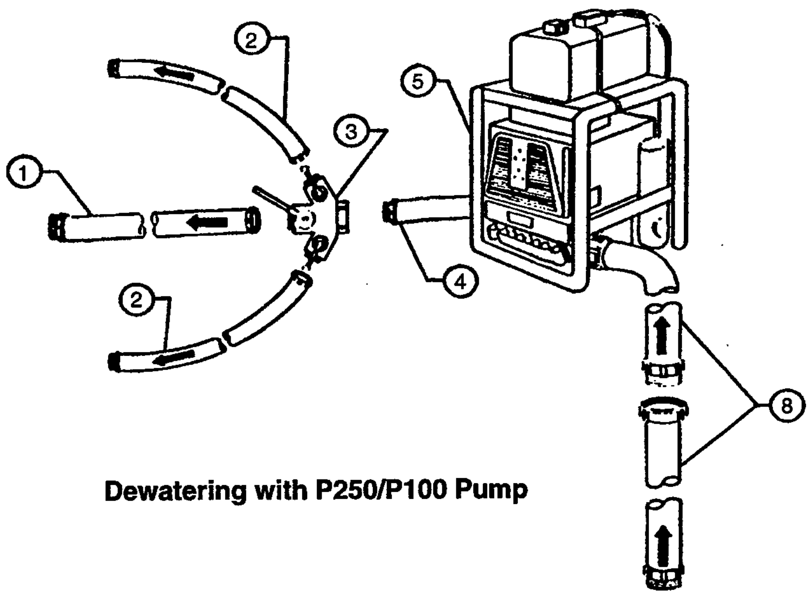
Fig. 12 – Wooden K-type shoring, Ref. (d)



ITEM	QTY	EQUIPMENT
1	1	SHORING TOOL KIT
2	2	ADJUSTABLE 6-11 FT STEEL SHORES
3	2	HORIZONTAL SUPPORT ACROSS STIFFENER - 4" x 4" x 4' STRONGBACKS
4	2	"C" CLAMP
5	1	HORIZONTAL SUPPORT TO SECURE SHORE AT TOP - 4" x 4" x 6'
6	1	HORIZONTAL SUPPORT TO SECURE SHORE FOOT AT BOTTOM - 4" x 4" x 6'
7	1	VERTICAL SHORE USED TO ANCHOR SHORE FEET
8	10	2" LAG BOLTS
9	3	4" LAG BOLTS
10	5	WEDGES (2" x 4" x 8")

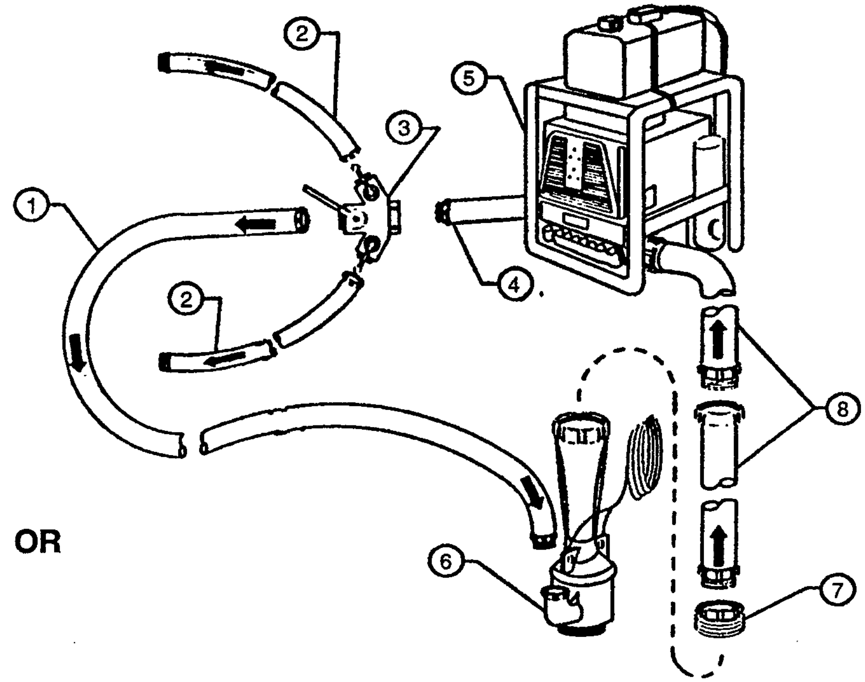
Fig. 13 – Wood/metal combination K-shore, Ref. (d)

ITEM	QTY	EQUIPMENT
1	1	2-2 1/2" x 50' FIREHOSE
2	2	1-1/2" x 50' FIREHOSE
3	1	TRIGATE, 2-1/2" INLET x (1) 2-1/2" & (2) 1-1/2" OUTLETS
4	1	2-1/2" x 2-1/2' JUMPER DISCHARGE HOSE
5	1	P250 MOD 2 PUMP W/ JP5 FUEL TANK
6	1	2-1/2" EDUCTOR, PERI-JET W/ 2" x 50' HANDLING LINE
7	1	ADAPTER - 3" FEMALE TO 4" MALE FITTING
8	Note 1	3" x 10' HARD RUBBER SUCTION HOSE
Note: Three or more lengths of suction hose required for lifts over 20'		



Dewatering with P250/P100 Pump

OR



Dewatering with Combination of Eductor and P250/P100 Pump

Fig. 14 – P250/P100 pump configurations for suction lifts under 6.1 m (20 ft), Ref. (d)

hose to the eductor. A discharge hose was connected to the eductor and lowered into the compartment with the foot valve. The pumped water was discharged overboard. This configuration is also shown in Fig. 14.

When personnel dewatered using the firemain to activate the 38 mm (1.5 in.) or 64 mm (2.5 in.) eductors, the hoses and eductors were rigged as shown in Figs. 15 and 16, respectively. The suction hose was connected to the eductor and to the fireplug (FPL 1-96-2) and the discharge hose was connected to the eductor and the overboard discharge at frame 96 on the main deck. After the hoses were connected, the eductor was lowered into the flooded compartment. With the eductor in the space, the fireplug was opened allowing water to flow through the eductor. The firemain pressure was approximately 7.6 bar (110 psi) at the fireplug for all of the dewatering tests.

7.4 Hull Repair Procedures

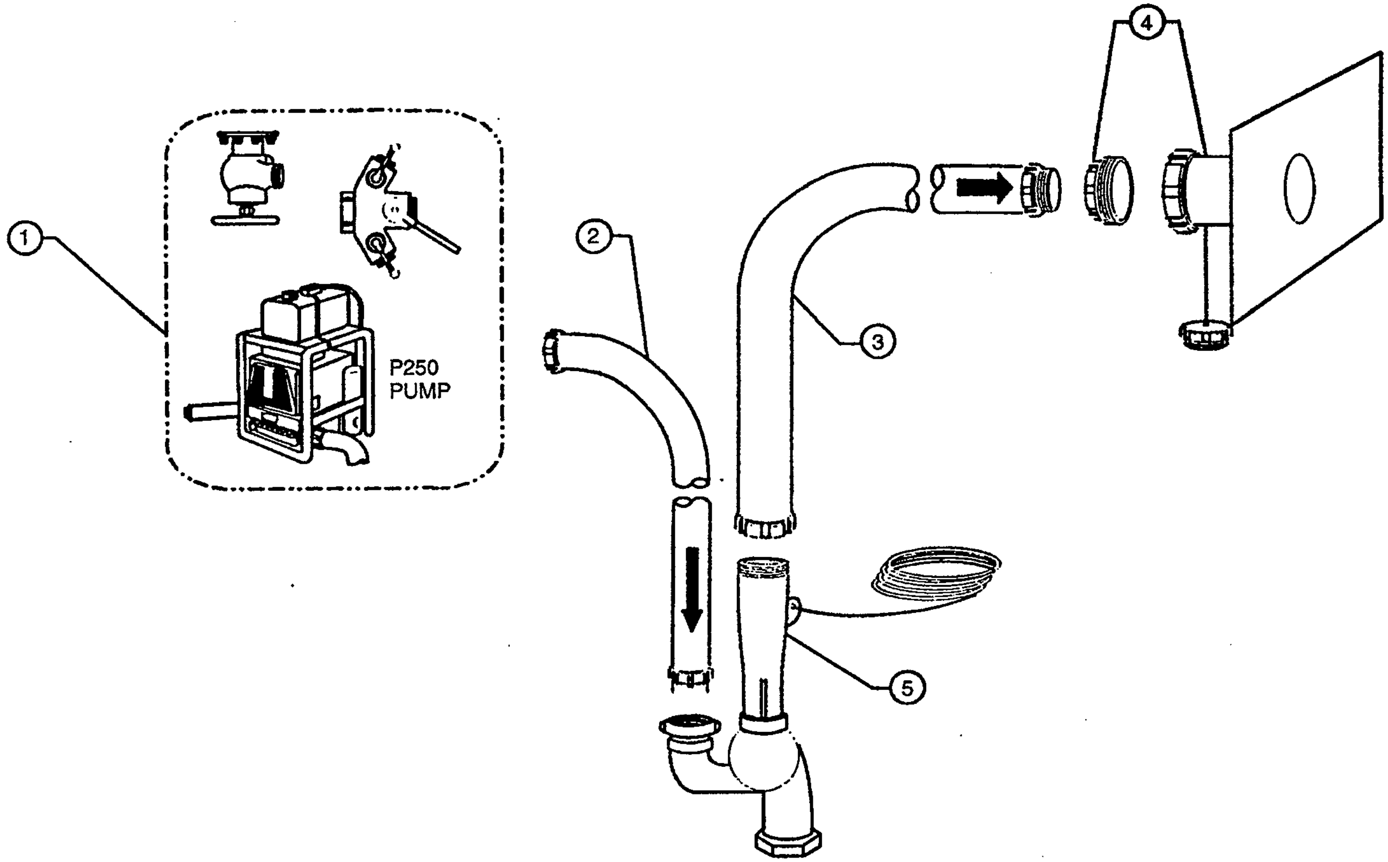
All of the hull repair tests were performed in the Upper Wet Compartment using the double hull tank. The hull damages included holes resulting from implosions and explosions. Temporary repairs were effected using the bucket and plate patches in conjunction with wood and metal "I" shoring. The procedures for each of these repairs, shown in Figs. 17-20, are essentially the same.

The first step in these hull repairs was to gather all of the necessary shoring in the flooding compartment. Once the shoring was ready to be put in place, the bucket/plate patch was held in place over the rupture. With the patch in place the shoring was set in place. Adjustments were made using wedges. When metal shoring was used, wedges were not necessary.

8.0 MEASURES OF PERFORMANCE

The results of these tests focused primarily on the effectiveness of the repair activity and the time to complete the repair. The time to complete the repair was recorded by both the on-scene observers and the control room. The effectiveness of the repair was determined by the on-scene observers and analysis of the data. The on-scene observers made their judgements based on a set of effectiveness criteria. They determined if the repair was effectively completed in accordance with Naval Ship Technical Manual (NSTM) Chapter 079 Volume 2 (reference (f)). This determination resulted in either an effective, marginal, or ineffective rating from the on-scene observers. Data analysis was required for the pipe patching and dewatering tests to determine if the repair satisfied the quantitative criteria. The effectiveness criteria for each repair activity are shown in Table 1. The overall effectiveness is a combination of the qualitative effectiveness, determined by the on-scene observer, and the quantitative effectiveness. If either of these was marginal or ineffective then the overall effectiveness was judged to be marginal or ineffective.

The tests were numbered to provide an indication of the test order. For example, test 3-08 was the eighth test conducted on the third day of testing. If this test was repeated then the repeat test would have been identified as 3-08-2.



ITEM	QTY	EQUIPMENT
1	1	ANY WATER SOURCE PROVIDING 1-1/2" OUTLET
2	1	1-1/2" x 50' FIREHOSE
3	1	2-1/2" x 50' FIREHOSE
4	1	4" OVERBOARD DISCHARGE CONNECTION W/ INSTALLED ADAPTER-4" MALE TO 2-1/2" FEMALE FITTING AND CAP (REMOVE CAP)
5	1	1-1/2" EDUCTOR W/ HANDLING LINE

Fig. 15 – 1-1/2" Eductor actuating from 1-1/2" fireplug or P250 pump, Ref. (d)

ITEM	QTY	EQUIPMENT
1	1	1-1/2" WATER OUTLET - ANY SOURCE
2	1	4" OVERBOARD DISCHARGE CONNECTION W/ INSTALLED ADAPTER - 4" MALE TO 2-1/2" FEMALE FITTING AND CAP (REMOVE AS UNIT)
3	1	ADAPTER - 4" DOUBLE MALE FITTING
4	1	4" x 50' FIREHOSE
5	1	2-1/2" PERI-JET EDUCTOR W/ HANDLING LINE
6	1	1-1/2" FIREHOSE
7	1	2-1/2" S-TYPE EDUCTOR W/ HANDLING LINE

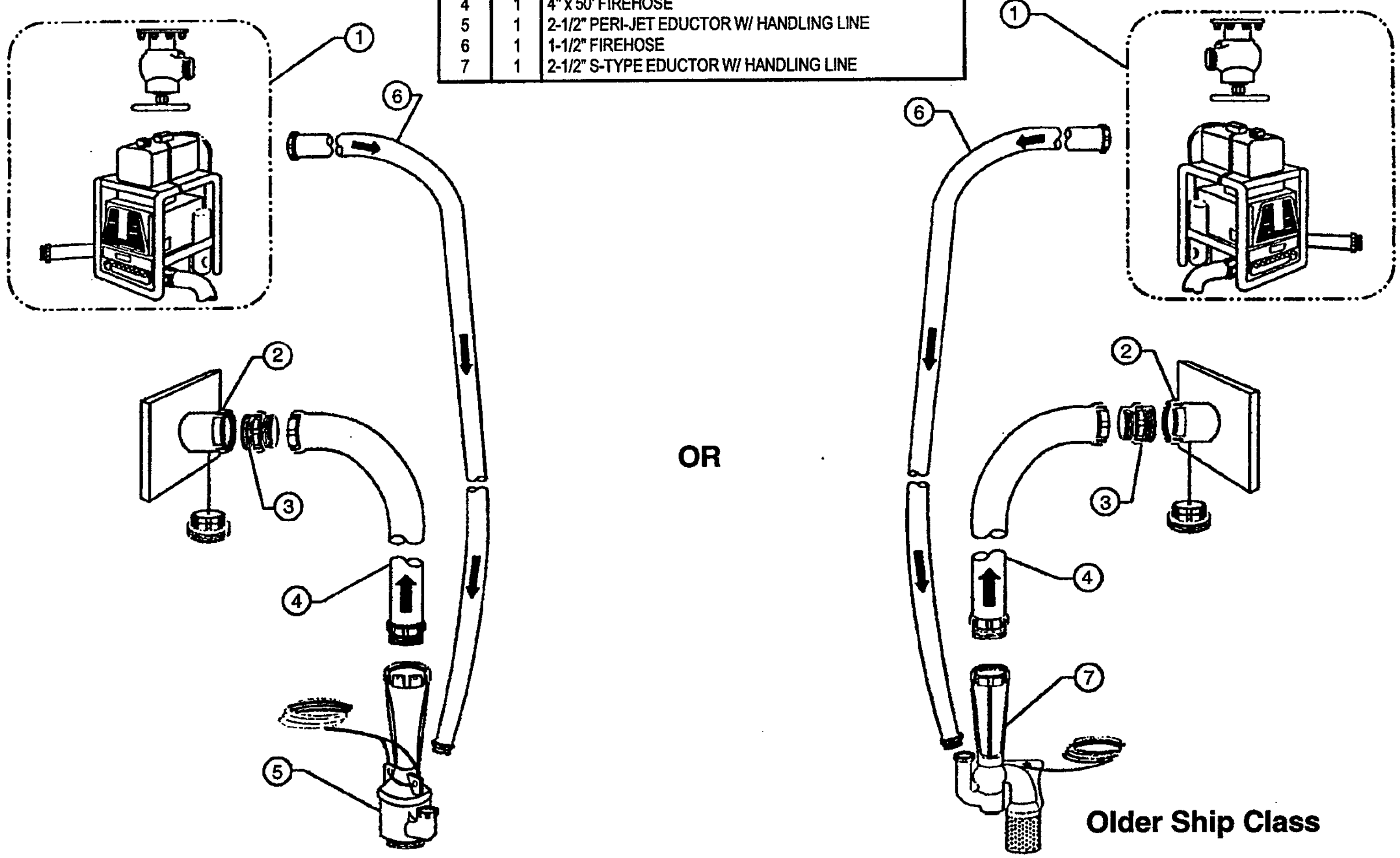


Fig. 16 – 2-2 1/2" Eductor actuating from 1-1/2" fireplug or P250 pump, Ref. (d)

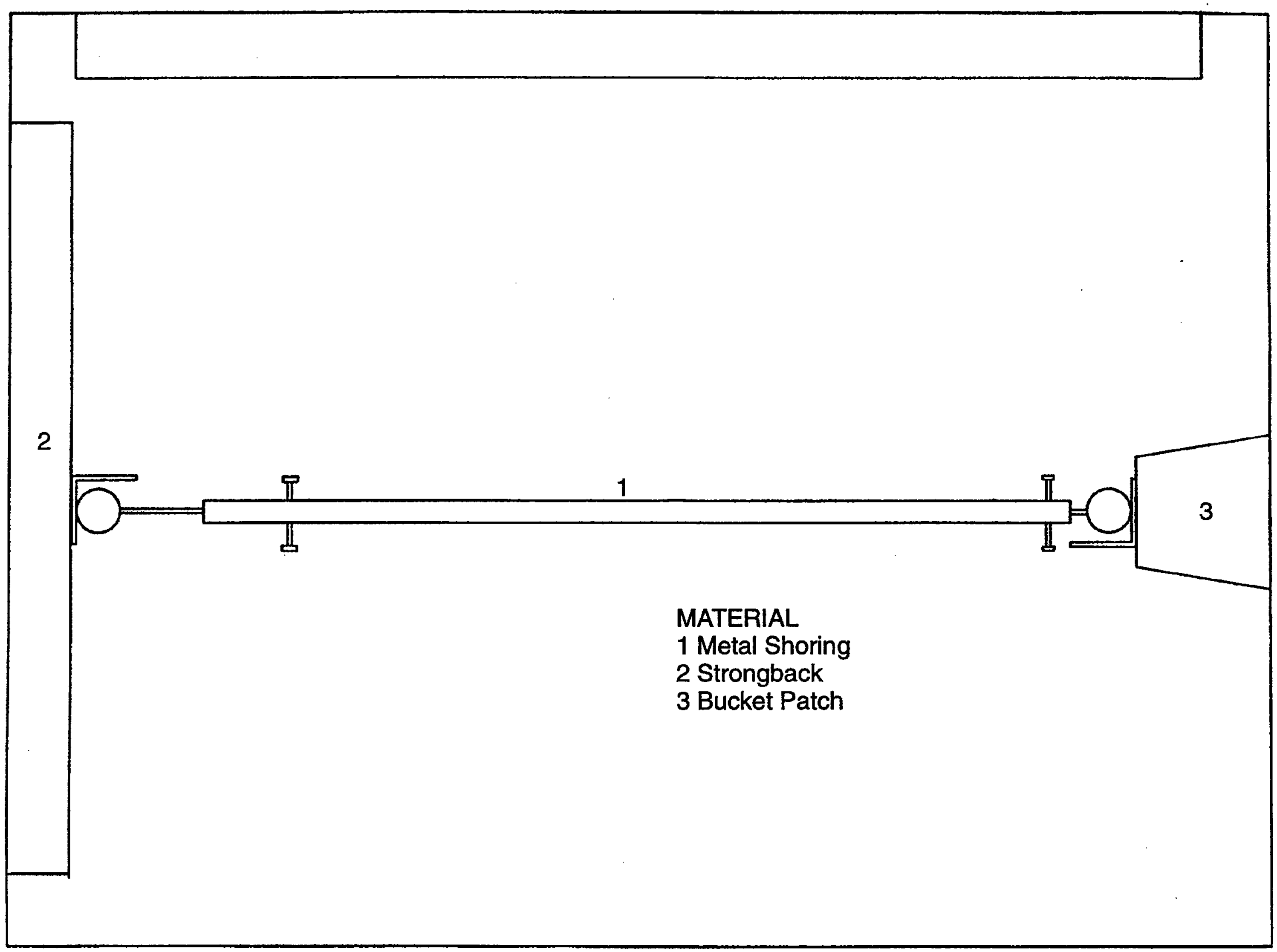


Fig. 17 – Bucket patch with metal I-shoring

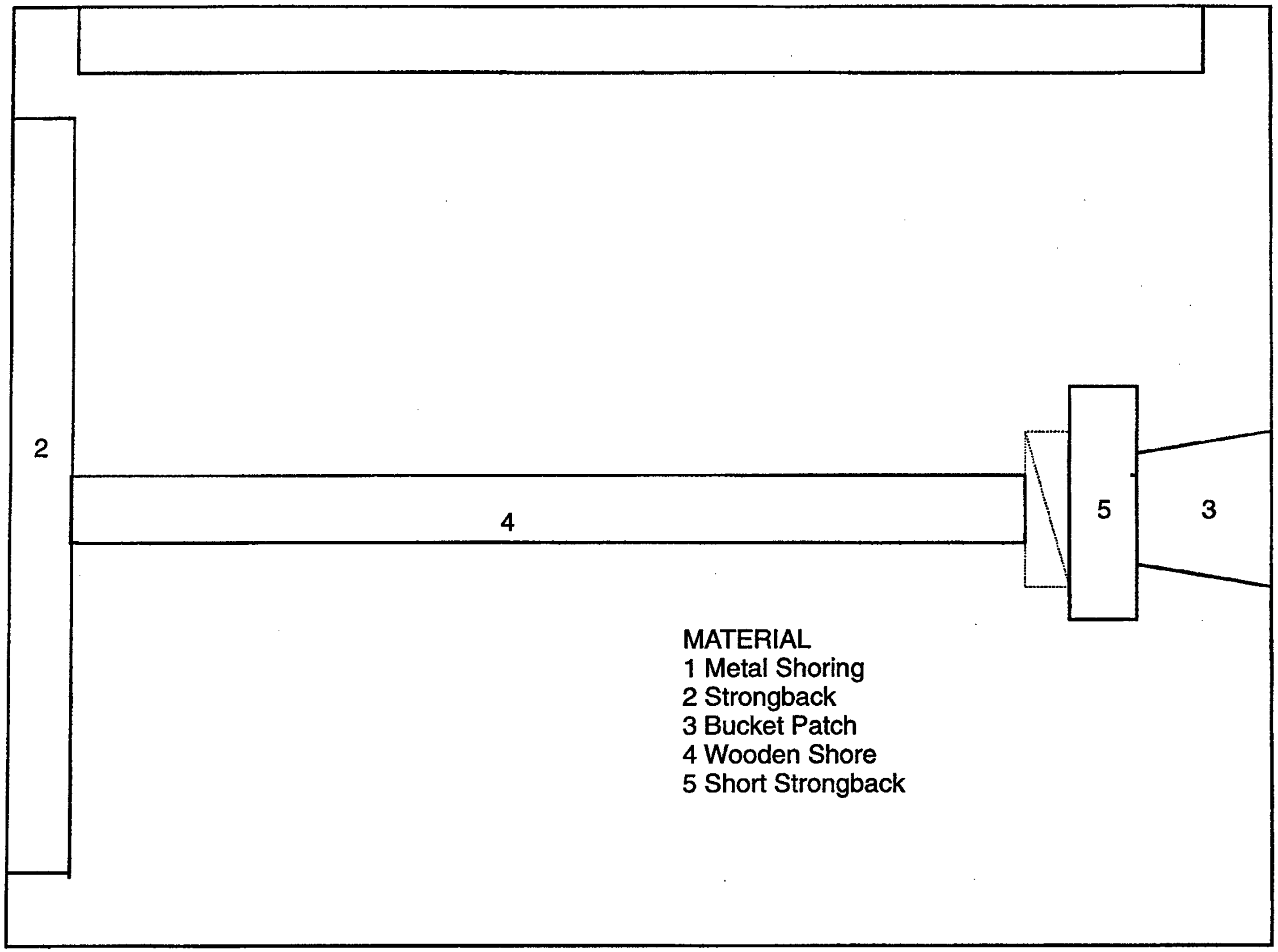


Fig. 18 – Bucket patch with wooden shoring

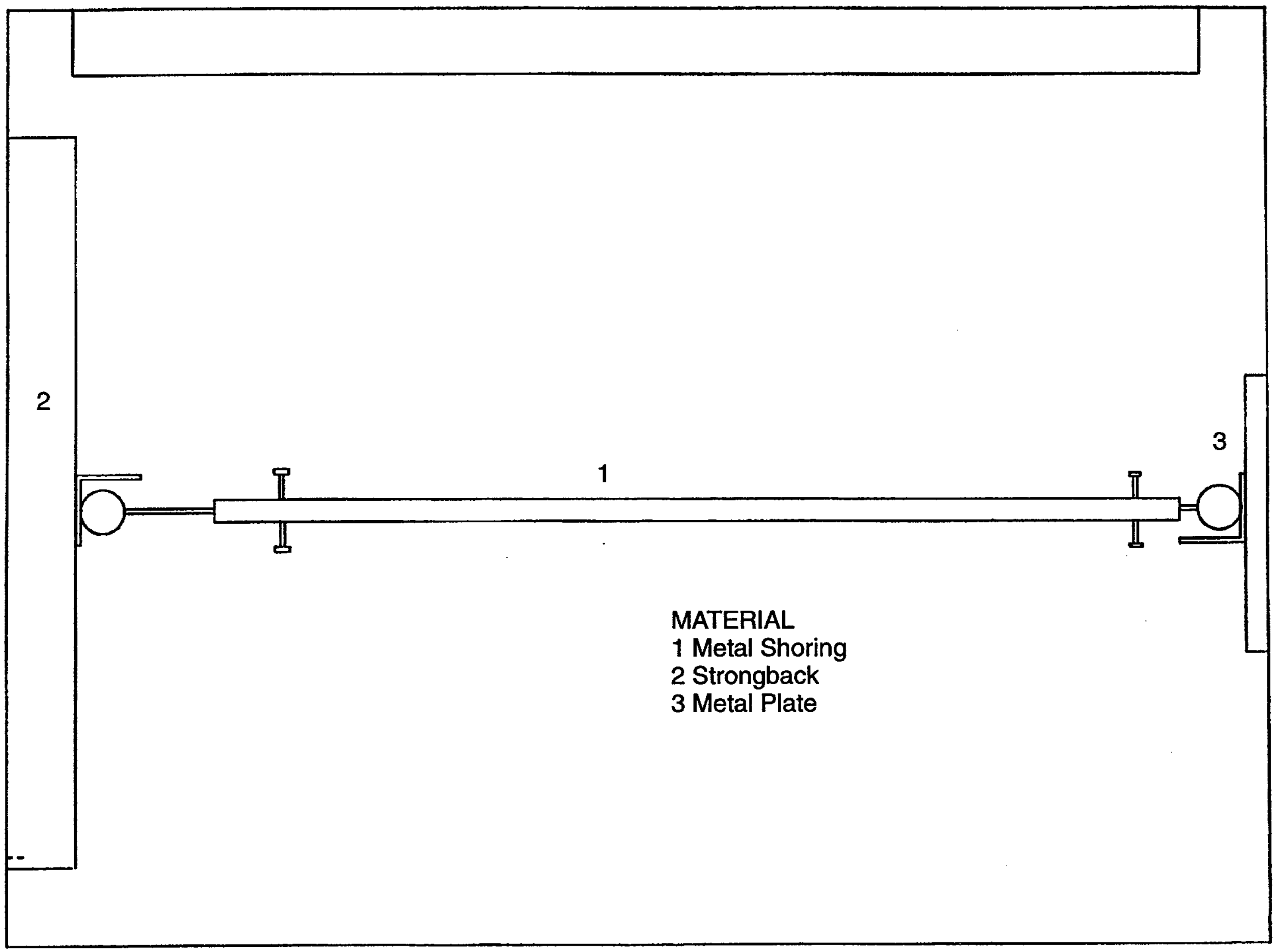


Fig. 19 – Metal plate with metal I-shoring

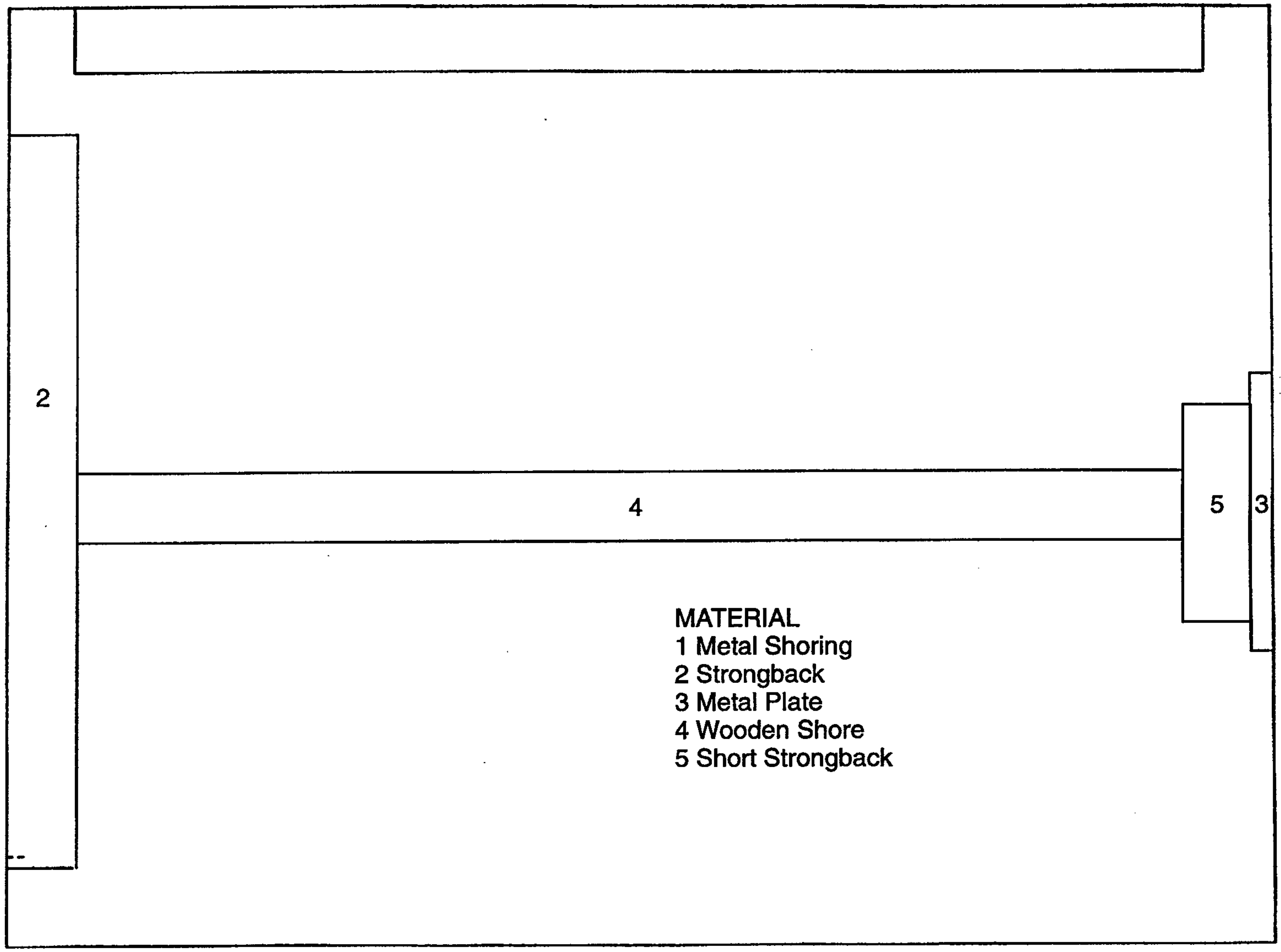


Fig. 20 – Metal plate with wooden shoring

Table 1. Summary of Effectiveness Criteria

Repair	Effectiveness Criteria
Pipe patch - Jubilee patch	time to complete repair < 45 minutes
	90-95% reduction in flow
Pipe patch - banding kit	time to complete repair < 45 minutes
	90-95% reduction in flow
Shoring	time to complete repair < 45 minutes
	structurally sound shore
Dewatering	time to rig dewatering equipment
	time to sustain dewatering (time of water discharge through hose minus the rig time)
	dewatering rate
Hull patch	time to complete repair < 45 minutes
	reduction in flow rate such that it is less than the assumed dewatering rate of 946 Lpm (250 gpm)

8.1 Results of Pipe Patching Tests

A total of 15 pipe patching tests were conducted on isolated (non-pressurized) systems. With the system isolated, there was no water flowing through the rupture during the repairs. Both the pipe rupture and repair method were varied. Two different pipe ruptures and three different repair methods were used, resulting in 6 different scenarios. Each test scenario was scheduled to be repeated three times, resulting in a total of 18 tests. However, the Fleetpak manufacturer did not supply an adequate amount of material to perform each of the Fleetpak tests. As a result, tests 4-09, 5-06, and 6-09 were not performed. Tests 4-09 and 5-06 were chill water repairs and test 6-09 was a firemain repair. All of the pipe repairs were performed by the same repair team.

Table 2 summarizes the data for each of the pipe patching tests. Included in this Table are the following: (1) test number, (2) test scenario, (3) repair method, (4) initial static pressure, (5) initial residual pressure in the water line with water flowing, (6) flow rate through the pipe rupture before repair initiation, (7) residual pressure in the water line at the completion of the test, (8) flow rate through the pipe rupture at the completion of the test, (9) repair time, and (10) overall effectiveness. The overall effectiveness was based on the qualitative data recorded by the on-scene observer (i.e. proper technique) and the effectiveness of the repair in reducing the flow through the rupture.

Table 2. Summary of Pipe Patching Tests

Test	Damage	Repair Method	Initial Static Pressure (bar (psi))	Initial Residual Pressure (bar(psi))	Initial Flow (Lpm(gpm))	Residual Pressure after Repair (bar(psi))	Residual Flow (Lpm(gpm))	Repair Time (min:sec)	Effectiveness
2-09	5 cm (2 in.) Chill Water	EWARP	4.1 (60)	0 (0)	57 (15)	4.2 (61)	0 (0)	6:44	effective
4-03	5 cm (2 in.) Chill Water	EWARP	4.1 (60)	0 (0)	57 (15)	4.1 (60)	0 (0)	6:17	effective
6-03	5 cm (2 in.) Chill Water	EWARP	4.1 (60)	0.1 (2)	57 (15)	4.3 (63)	0 (0)	6:35	effective
1-03	5 cm (2 in.) Chill Water	Fleetpak	4.1 (60)	0 (0)	57 (15)	0 (0)	57 (15)	10:00	ineffective
4-09	5 cm (2 in.) Chill Water	Fleetpak							see Note 1
5-06	5 cm (2 in.) Chill Water	Fleetpak							see Note 1
1-06	5 cm (2 in.) Chill Water	Soft Patch	4.1 (60)	0 (0)	57 (15)	4.1 (60)	3.8 (1)	26:14	effective
3-09	5 cm (2 in.) Chill Water	Soft Patch	4.1 (60)	0.2 (3)	49 (13)	3.8 (55)	5.7 (1.5)	35:20	effective
5-09	5 cm (2 in.) Chill Water	Soft Patch	4.1 (60)	0 (0)	57 (15)	4.1 (60)	0 (0)	23:11	effective
2-06	10 cm (4 in.) Firemain	EWARP	8.3 (121)	6.1 (88)	280 (74)	7.9 (115)	4.5 (1.2)	6:15	effective
3-03	10 cm (4 in.) Firemain	EWARP	8.3 (121)	6.1 (89)	303 (80)	8.4 (122)	5.7 (1.5)	5:08	effective
5-03	10 cm (4 in.) Firemain	EWARP	8.3 (121)	5.9 (86)	265 (70)	7.7 (112)	3.8 (1.0)	5:05	effective
2-03	10 cm (4 in.) Firemain	Fleetpak	8.3 (121)	6.2 (90)	284 (75)	6.3 (91)	265 (70)	18:33	ineffective
3-06	10 cm (4 in.) Firemain	Fleetpak	8.3 (121)	6.6 (95)	288 (76)	6.8 (98)	272 (72)	11:13	ineffective
6-09	10 cm (4 in.) Firemain	Fleetpak							see Note 1
1-09	10 cm (4 in.) Firemain	Soft Patch	8.3 (121)	5.9 (85)	333 (88)	7.9 (115)	13.0 (3.5)	34:09	effective
4-06	10 cm (4 in.) Firemain	Soft Patch	8.3 (121)	5.9 (85)	326 (86)	6.2 (90)	284 (75)	17:21	ineffective
6-06	10 cm (4 in.) Firemain	Soft Patch	no data	no data	348 (92)	no data	0 (0)	17:38	effective

1 Manufacturer did not supply enough material to perform these tests.

The EWARP patch was effective on both the chill water and pipe rig ruptures. In both scenarios the repair time was less than seven minutes and resulted in the reduction of flow to less than 7.6 Lpm (2.0 gpm). The EWARP was particularly effective on the chill water rupture, reducing the flow to essentially zero for all three tests (2-09, 4-03, and 6-03). For the firemain rupture the flow was reduced to between 3.8 and 5.7 Lpm (1 and 1.5 gpm) for all three tests (2-06, 3-03, and 5-03). The soft patch was also effective on the chill water rupture, but required four to six times the time to effect than the EWARP. The soft patch required more than 23 minutes to install for all three tests. In test 3-09 the team required 35:20 to install the soft patch. The flow was reduced to 3.8, 5.7, and 0 Lpm (1, 1.5, and 0 gpm) for tests 1-06, 3-09, and 5-09, respectively. The soft patch was effective on the firemain rupture in tests 1-09 and 6-06, but ineffective in test 4-06. In test 1-09 the repair team required 34:09 to effect the repair and reduced the flow to 13.2 Lpm (3.5 gpm). In test 6-06 the flow was reduced to almost zero in 17:38. Test 4-06 was ineffective because the residual flow was 284 Lpm (75 gpm). This was believed to be the result of an improperly placed gasket. In each of the three Fleetpak tests conducted (1-03, 2-03, and 3-06), the Fleetpak repair was ineffective. The Fleetpak resulted in almost no reduction in flow. In each case the patch was blown off of the pipe when the water lines were pressurized to test the patch. In addition, the amount of material suggested for each rupture by the manufacturer was inadequate.

Based on the results of these tests, the EWARP appears to be more effective and easier to install than either the soft patch or the Fleetpak patch for the scenarios tested. The soft patch is nearly as effective in reducing flow as the EWARP patch but requires significantly more time to install. The Fleetpak patch was ineffective in each of the scenarios tested. The amount of Fleetpac material suggested by the manufacturer to repair the pipe ruptures was inadequate. The manufacturer indicated that one Fleetpac kit would be adequate for each test. However, two kits were used by the repair team for each test. As a result, all of the material was used before all of the tests could be conducted.

8.2 Results of Shoring Tests

A total of 13 shoring tests were conducted during this test series. These tests involved two types of shores ("H" and "K") constructed with two types of materials (wood only and wood and metal). Each test scenario was repeated three times. An additional wooden "H" shore test (2-07) was conducted accidentally. Test 2-07 should have been a wooden "K" shore, and was repeated as test 2-07-2.

A summary of the shoring test results is included in Table 3. This Table includes (1) the test number, (2) the type of shore constructed, (3) the repair time, and (4) the overall effectiveness of the repair. For the shoring tests, the overall effectiveness was a qualitative assessment made by the on-scene observer, based on the time to complete the repair and the structural integrity of the shore.

In each of the shoring scenarios, the first test was ineffective. This may indicate that the repair team members did not have adequate experience/training in constructing these shores. For the wooden "H" and "K" shores all of the subsequent tests for that scenario were effective. For the combination shores only the final tests were effective. The wooden "K" shore was effectively constructed in the second and third tests. The repair time for test 3-04 was 30:57 and 27:56 for test 2-07-2. For the combination "K" shore, tests 1-07 and 2-10 were ineffective and the repair times were 22:12 and 41:31, respectively. Test 3-01, the only effective combination "K" shore, had a repair time of 12:04. The repair times for both types of "K" shores are similar to those observed in the May 1995 test series (reference (a)). For the combination "K" shore, repair times of 17:00, 12:28, and 12:23 were observed for the first, second, and third tests, respectively. The wooden "K" shore was effectively constructed in the first and third tests in the May 1995 test series. The repair times for the first and third tests were 42:32 and 27:37, respectively.

Table 3. Summary of Shoring Tests

Test	Shore	Repair Time (min:sec)	Effectiveness
1-01	K-shore - wood	46:31	ineffective
3-04	K-shore - wood	30:57	effective
2-07-2	K-shore - wood	27:56	effective
1-07	K-shore - wood/metal	22:12	ineffective
2-10	K-shore - wood/metal	41:31	ineffective
3-01	K-shore - wood/metal	12:04	effective
1-04	H-shore - wood	57:52	ineffective
2-04	H-shore - wood	41:24	effective
2-07	H-shore - wood	20:05	effective
3-07	H-shore - wood	18:02	effective
1-10	H-shore - wood/metal	33:27	ineffective
2-01	H-shore - wood/metal	30:51	marginal
3-10	H-shore - wood/metal	25:03	effective

The wooden "H" shore was effectively constructed in all of the tests except the first, test 1-04. The wooden "H" shore was effectively constructed in 41:24 in test 2-04 and 20:05 in test 2-07. Since test 3-07 was the fourth test of the wooden "H" shore and none of the other shoring methods were tested four times, test 3-07 is not included in this analysis. The combination "H" shore was only effectively installed in one test (test 3-10) and required 25:03 to construct.

Based on the results of the July tests, it appears that the combination "K" shore can be constructed quicker than any of the other shoring methods evaluated in this test series. The combination "H" shore required slightly more time to construct than the wooden "H" shore. The wooden "H" and "K" shores were effectively constructed more often than their corresponding combination shores. There appears to be evidence of a "learning curve" effect in the shoring tests. For example, the repair time for the wooden "K" shore was reduced from 46:31 in the first test to 27:56 in the third test. A statistical analysis (reference (g)) determined that "learning curve" effects were present in the May test series. The fact that the first test for each scenario was ineffective may indicate that the members of the repair team were not adequately trained in the construction of each type of shore.

Comparison of the results from the May and July tests indicate that there are significant differences in the capabilities of the two repair teams. In the May test series, the combination K-shore was installed effectively in 17:00, 12:28, and 12:23 in the first, second, and third tests, respectively. In the July test series, this shore was installed ineffectively in 22:12 and 41:31 in the first and second tests and effectively in 12:04 in the third test. The differences in the effectiveness of the repairs may indicate differences in the amount of shipboard training.

8.3 Results of Dewatering Tests

A total of 22 dewatering tests were performed. All of these tests were performed by the same repair team. Seven different dewatering equipment configurations were evaluated, including (1) 38 mm (1.5 in.) eductor off of the firemain, (2) 64 mm (2.5 in.) eductor off of the firemain, (3) P-100 with a foot valve, (4) P-100 with a 38 mm (1.5 in.) eductor, (5) P-250 with a 38 mm (1.5 in.) eductor, (6) P-250 with a 64 mm (2.5 in.) eductor, and (7) P-250 with a foot valve. All of the tests began with an initial water depth of 0.6 m (2.0 ft) in the lower wet compartment and involved a lift of approximately 6 m (20 ft).

Three tests were performed for each of the equipment configurations, with one exception. Test 1-08 had to be aborted due to a pump failure. The pump was fueled with gasoline instead of JP-5. Since the refueling was not the repair team's responsibility, the test was repeated (1-08-2). All of the dewatering tests were performed by the same team. After the fifth day of testing, one of the team members was replaced due to a medical condition.

A summary of the dewatering tests is included in Table 4. This Table includes (1) the test number, (2) the dewatering equipment configuration, (3) the calculated dewatering rate, (4) the equipment rig time, (5) any additional time required to sustain dewatering (e.g., time required to prime and start pump), and (6) the overall effectiveness. Dewatering rates were calculated using the change in the water level with respect to time and the net floor area of the compartment. In several instances the rig times were not recorded. In these cases the total time required to initiate dewatering is included in the dewatering time column.

The majority of the tests were determined to be effective. Tests 3-05, 4-05, and 6-02 were determined to be marginal. In these tests the dewatering team failed to prevent kinks in the suction hose. These kinks prohibited the pump/equipment from operating at maximum capacity. Tests 4-02 and 4-08 were also determined to be marginal. In these tests the repair team did not use the correct starting procedure for the P-250 pump. In test 4-02 the dewatering team operated the primer after the pump was started.

In test 4-08 the dewatering team failed to put the pump switch in the run position once the pump pressure was above 4 bar (60 psi). Although the starting procedures were incorrect, the team was able to begin dewatering in each of these tests. Two tests (tests 2-05 and 6-05) were rated ineffective, because the dewatering team had to be instructed on the proper priming and starting procedures for the P-250 and P-100 pumps.

Based on the limited amount of rig time data, it appears that the differences in the equipment rig times were significant. The equipment rig times ranged from 2:00 in test 3-08 to 10:30 in test 2-08. Additional data would allow a more thorough analysis of the equipment rig times. There were also significant differences in the total time required to sustain dewatering. The total times required to begin dewatering (dewatering time) for the 38 mm (1.5 in.) and 64 mm (2.5 in.) eductors off of the firemain were the lowest of all of the equipment configurations. The dewatering time for the 38 mm (1.5 in.) eductor of off the firemain was 2:00 in test 3-08. The dewatering time for the 64 mm (2.5 in.) eductor off of the firemain was 4:00 in test 4-05. The P-250 with a foot valve and the P-250 with a 64 mm (2.5 in.) eductor had the highest dewatering times. The dewatering times for the P-250 with a foot valve were

Table 4. Summary of Dewatering Tests

Test	Pump Configuration	Dewatering Rate (Lpm (gpm))	Rig Time (min:sec)	Time to Sustain Dewatering (min:sec)	Total Dewatering Time (min:sec)	Effectiveness
1-02	3.8 cm (1.5 in.) eductor off firemain	no data	not recorded	4.00 (total)	4:00	effective
3-08	3.8 cm (1.5 in.) eductor off firemain	273 (60)	2:00	0.00	2:00	effective
7-04	3.8 cm (1.5 in.) eductor off firemain	273 (60)	2:03	0.00	2:03	effective
2-08	6.4 cm (2.5 in.) eductor off firemain	796 (175)	10:30	2:30	13:00	effective
4-05	6.4 cm (2.5 in.) eductor off firemain	455 (100)	not recorded	4:00 (total)	4:00	marginal
6-02	6.4 cm (2.5 in.) eductor off firemain	455 (100)	3:00	2:00	5:00	marginal
1-05	P-100 with foot valve	455 (100)	not recorded	6:00 (total)	6:00	effective
5-05	P-100 with foot valve	636 (140)	not recorded	5:00 (total)	5:00	effective
6-05	P-100 with foot valve	no data	4:09	2:51	7:00	ineffective
1-08	P-250 with 3.8 cm (1.5 in.) eductor					see Note 1
1-08-2	P-250 with 3.8 cm (1.5 in.) eductor	818 (180)	6:10	1:50	8:00	effective
5-02	P-250 with 3.8 cm (1.5 in.) eductor	909 (200)	not recorded	7:00 (total)	7:00	effective

Table 4. Summary of Dewatering Tests (Continued)

Test	Pump Configuration	Dewatering Rate (Lpm (gpm))	Rig Time (min:sec)	Time to Sustain Dewatering (min:sec)	Total Dewatering Time (min:sec)	Effectiveness
7-06	P-250 with 3.8 cm (1.5 in.) eductor	909 (200)	9:41	2:19	12:00	effective
3-02	P-250 with 6.4 cm (2.5 in.) eductor	1136 (250)	5:10	3:50	9:00	effective
4-08	P-250 with 6.4 cm (2.5 in.) eductor	1182 (260)	not recorded	14:00 (total)	14:00	marginal
6-08	P-250 with 6.4 cm (2.5 in.) eductor	no data	8:35	5:25	14:00	effective
2-02	P-250 with foot valve	1364 (300)	not recorded	8:00 (total)	8:00	effective
4-02	P-250 with foot valve	1023 (225)	not recorded	9:00 (total)	9:00	marginal
5-08	P-250 with foot valve	no data	not recorded	11:00 (total)	11:00	effective
2-05	P-100 with 3.8 cm (1.5 in.) eductor	545 (120)	6:00	2:00 after restarted	8:00	ineffective
3-05	P-100 with 3.8 cm (1.5 in.) eductor	773 (170)	5:45	12:15	18:00	marginal
7-02	P-100 with 3.8 cm (1.5 in.) eductor	636 (140)	5:24	1:36	7:00	effective

1 Ineffective due to pump failure - wrong fuel used in pump

8:00, 9:00, and 11:00 for tests 2-02, 4-02, and 5-08, respectively. The dewatering times for the P-250 with a 64 mm (2.5 in.) eductor were 9:00, 14:00, and 14:00 for tests 3-02, 4-08, and 6-08, respectively.

The dewatering times for these tests are significantly higher than those observed in the May test series. For example, for the P-100 with foot valve, in the May series the total times required to sustain were 2:00 in the first test and 1:37 in the second test. In the July test series the dewatering times were 6:00, 5:00, and 7:00 in the first, second, and third tests, respectively. The differences between the May and July dewatering times are at least partly the result of the additional 3 m (10 ft) of lift. The lift in the May test series was 3 m (10 ft) compared to 6.1 m (20 ft) in the July test series. The increased lift resulted in the need for additional lengths of suction hose. It is believed that differences in the individual capabilities/training of the two repair teams may also be responsible for some of the differences.

The calculated dewatering rates were proportional to the equipment rig times (i.e. a longer rig time resulted in a larger dewatering rate). The 38 mm (1.5 in.) eductor off of the firemain had the lowest dewatering time and the lowest rig rate (227 Lpm (60 gpm) in tests 3-08 and 7-04). The P-250 with a foot valve and the P-250 with a 64 mm (2.5 in.) eductor had the highest rig times and the highest dewatering rates (1139 Lpm (300 gpm) in test 2-02 and 946 Lpm (250 gpm) in test 3-02. The dewatering rates calculated in the July test series do not correspond with those calculated for the May test series. The dewatering rates calculated for the May test series were not as accurate as those calculated for the July test series. The compartment used for the May dewatering tests (the Upper Wet Compartment) contained several pieces of furniture (bunks and lockers). Due to the volume of these items, the compartment volume changed with respect to height. The dewatering rates calculated for the May test series appeared to be significantly higher than the expected values. The compartment used in this test series did not contain any of these items and as a result produced more accurate calculations.

8.4 Results of Hull Repair Tests

A total of 9 hull repair tests were performed, involving two different hull ruptures and four different hull repair methods. The use of the plate and bucket patches with wood and metal shoring were used to repair explosion and implosion ruptures. Each scenario was scheduled to be tested two times. However, after test 4-10, the plate patch tests were performed without water flowing through the rupture to improve the safe conduct of the tests. The water pressure was too high for the repair team to maintain control of the plate patch. The potential for injury was determined to be too high, and as a result the remainder of the plate patch tests were performed without water flowing. The repairs were tested after being installed. Test 5-04 was secured prior to the completion of the test, when the ship's generator failed. All of the hull repair tests were performed by the same repair team.

A summary of the hull repair test data is contained in Table 5. This table includes (1) the test number, (2) the type of hull rupture, (3) the repair method, (4) the repair time, and (5) the overall effectiveness. The water level sensor in the double hull tank failed early in the test series, preventing the determination of the head pressure.

The plate patch was too difficult to handle to be safely used to repair actively flooding hull ruptures. Only one plate patch test (test 4-04) was completed with water flowing through the rupture. In this case the patch was effectively installed in 8:03. The plate patch was effectively installed in each of the tests where the water was secured until the repair was completed. Without water flowing, the plate patch was consistently installed in less than 9:30. In tests 5-01 and 7-03 the patch was installed in under five minutes. The box patch was installed ineffectively in all of the tests with the exception of tests 4-07 and 7-

01. In test 4-07, the repair was determined to be marginal. The repair was marginal because the shoring was not perpendicular to the patch and the gasket was not used. With the shoring not being perpendicular, there is a greater likelihood that the shoring could be pushed out of position by water pressure. The absence of a gasket allowed water to pass by the patch. In test 7-01 the box patch with wood shoring was installed effectively in 13:00.

Table 5. Summary of Hull Repair Tests

Test	Damage	Repair Method	Water Flowing (Yes/No)	Total Repair Time (min:sec)	Effectiveness
5-07	Explosion	Plate with wood shore	No	8:59	effective
7-03	Explosion		No	4:44	effective
4-10[1]	Explosion	Plate with metal shore	Yes		
7-07	Explosion		No	9:17	effective
4-07	Explosion	Box patch with wood shore	Yes	6:52	marginal
7-05	Explosion		Yes	13:10[1]	ineffective
5-04[2]	Explosion	Box patch with metal shore	Yes		
6-01	Explosion		Yes	15:00	ineffective
4-04[3]	Rip/Gash	Plate with wood shore	Yes	8:03	effective
6-10	Rip/Gash		No	9:09	effective
5-01	Rip/Gash	Plate with metal shore	No	3:11	effective
6-07	Rip/Gash		No	5:24	effective
5-10	Rip/Gash	Box patch with wood shore	Yes	15:00	ineffective
7-01	Rip/Gash		Yes	13:00	effective
4-01	Rip/Gash	Box patch with metal shore	Yes	15:02	ineffective
6-04	Rip/Gash		Yes	14:58	ineffective

1 Water secured at 13:10.
2 Test secured when power was lost.
3 Test terminated by safety team.

Based on the results of these tests, it does not appear that any of the methods tested are adequate methods for the repair of actively flowing hull ruptures under the conditions tested. The plate patch with wood or metal shoring was an effective repair when the water was secured. There were significant differences in the times required to install the plate patch with wood shoring compared to metal shoring. In tests 5-01 and 6-07 the plate patch with metal shoring was installed in 3:11 and 5:24, respectively. In tests 4-04 and 6-10 the plate patch with wood shoring was installed in 8:03 and 9:09, respectively. It should be noted that each of these tests, with the exception of test 4-04, was performed with the water secured. There does not appear to be any evidence of learning curve effects.

9.0 CONCLUSIONS

Preliminary analysis of the data collected during the July 1995 test series has been completed and the following observations can be made.

With respect to pipe patching, the EWARP was more effective and easier to install than either the soft patch or the Fleetpak patch. The soft patch was nearly as effective as the EWARP patch in reducing flow but required four to six times the amount of time to install. The Fleetpak patch was ineffective in each of the scenarios tested. The amount of Fleetpak material suggested by the manufacturer to repair the pipe ruptures was inadequate. As a result all of the material was used before all of the tests could be conducted.

Based on the results of these tests as well as the tests conducted during the May test series, it appears that the combination "K" shore can be constructed quicker than any of the other shoring methods evaluated in this test series. The combination "H" shore required slightly more time to construct than the wooden "H" shore. The wooden "H" and "K" shores were effectively constructed more often than the corresponding combination shores. The fact that the first test for each type of shore was ineffective may indicate the need for improvement in the shoring training program.

There were substantial differences in the total time required to begin dewatering and the dewatering rate. In general, the equipment configurations with the longer rig times had the higher dewatering rates. As a result, the more effective dewatering configuration may be one with a higher rig time, depending on the state of the compartment. In several of the tests kinks in the suction hose prevented the dewatering equipment from operating at maximum capacity. The need to inspect the suction hoses for kinks should be emphasized in the Naval Ship's Technical Manual, Chapter 079.

None of the hull repair methods tested were adequate for the repair of actively flowing hull ruptures. However, when the water was secured, the plate patch with wood or metal shoring was an effective repair. There were significant differences in the times required to install the plate patch with wood shoring compared to metal shoring. The box patch was not tested with the water secured. During the May 1995 test series (reference (a)), the bucket patch with "J" bolt was determined to be an effective hull repair method.

Other conclusions relative to manning can also be made based on the data collected during this test series. Based on the observations of the on-scene observers, the current manning requirements appear to be adequate, with two exceptions. First, if either the bucket or plate patch with shoring is to be used to repair an actively flowing hull rupture, an additional person may be necessary. This would result in a four person hull repair team. Second, if the shoring team were required to install a second shore in another location, the team would lose a member. One member of the repair team would be required to maintain a watch on the first shore. A 7.6 m (25 ft) retractable tape should be added to the shoring kit.

10.0 RECOMMENDATIONS

Based on the results and conclusions of this test series, there are several recommendations. 1) Differences in the rig and dewatering times and dewatering rates of the available dewatering equipment should be emphasized to aid in equipment selection. 2) The need to inspect suction hoses for kinks when dewatering should be emphasized in the Naval Ship's Technical Manual, Chapter 079. 3) The priming and starting procedures for the P-100 and P-250 pumps should be explained in detail in the Naval Ship's Technical Manual, Chapter 079. 4) Based on the results of both the May and July tests, the use of metal shoring materials should be considered for K-shores. 5) The plate patch should not be used to repair actively flowing hull ruptures. The plate patch could, however, be used to repair ruptures above the water line. 6) The EWARP patch should be used to repair isolated (non-pressurized) pipe systems. 7) The removal of the Fleetpak patch from the fleet should be considered.

11.0 ACKNOWLEDGMENTS

NRL is especially grateful to crew members of the USS BENFOLD as well as individuals from CINCLANTFLT for their participation. The individuals from the USS BENFOLD who participated were ENC Judy O'Brien, SK1 Glen VanVorst, DCC Brian Hock, DC3 Jason Brown, EN3 Errol Russell, and DC1 Derick Weathersby. The individuals from CINCLANTFLT who participated were HT1 Dan McKee and DC2 Lebaron Chestang.

12.0 REFERENCES

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(b) Carhart, H.W., Toomey, T.A., Williams, F.W., "The Ex-SHADWELL Full Scale Fire Research and Test Ship," NRL Memorandum Report 6074, Naval Research Laboratory, Washington, DC, October 6, 1987, re-issued September 1992.

(c) Naval Sea Systems Command, "Full Scale Damage Control Engineering Evaluations FY 95 Test Plan," NAVSEA Ltr 9555 03G1/76, April 28, 1995.

(d) "Damage Control and Firefighting Equipment Layout Booklet," NAVSEA-SS-100-AG-MAN-010, Naval Sea Systems Command, in preparation.

(e) Smith, D.E., "July Damage Control Test Plan," Memorandum, July 7, 1995.

(f) "Practical Damage Control," Naval Ships' Technical Manual, Chapter 079, Volume 2, Naval Sea Systems Command, December 15, 1979.

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Appendix A
Instrumentation Drawings

INSTRUMENT KEY

A	AUDIO
P	PRESSURE
V	VIDEO CAMERA
S	DOOR MICROSWITCH
T	THERMOCOUPLE TREE
U	ULTRASONIC FLOW METER
F	TURBINE FLOW METER

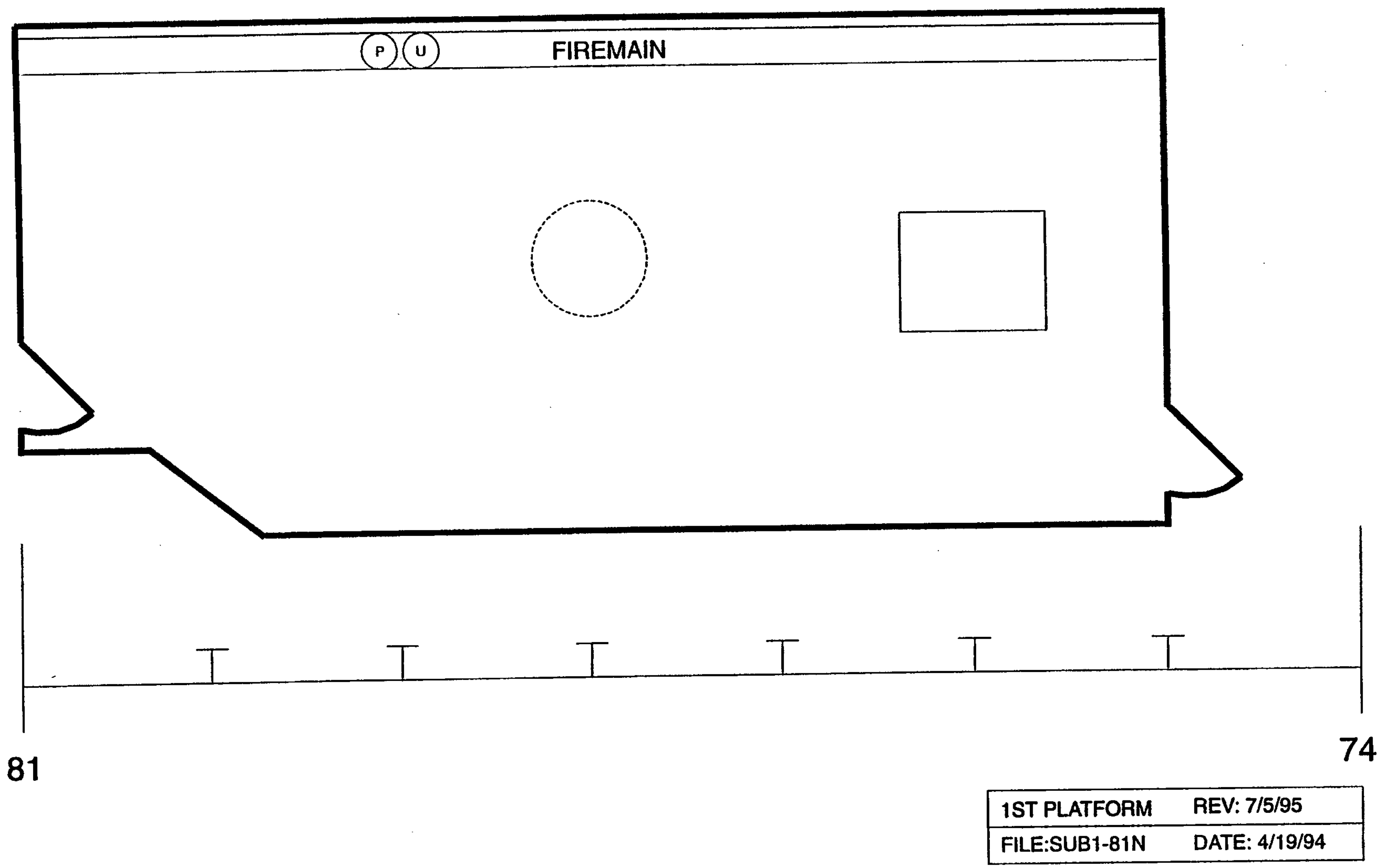

Fig. A1 – Combat systems instrumentation layout

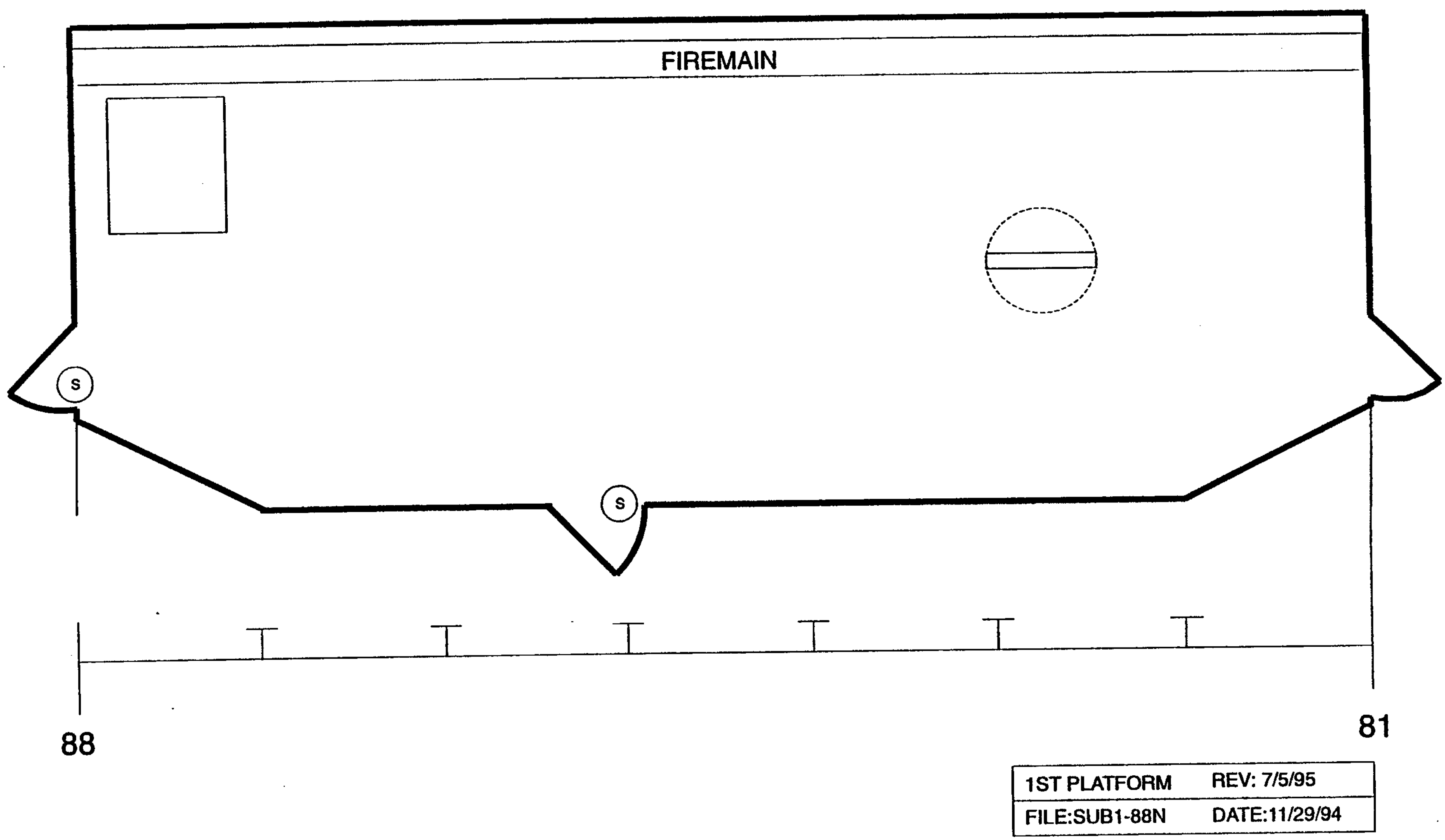

Fig. A2 -- Control room instrumentation layout

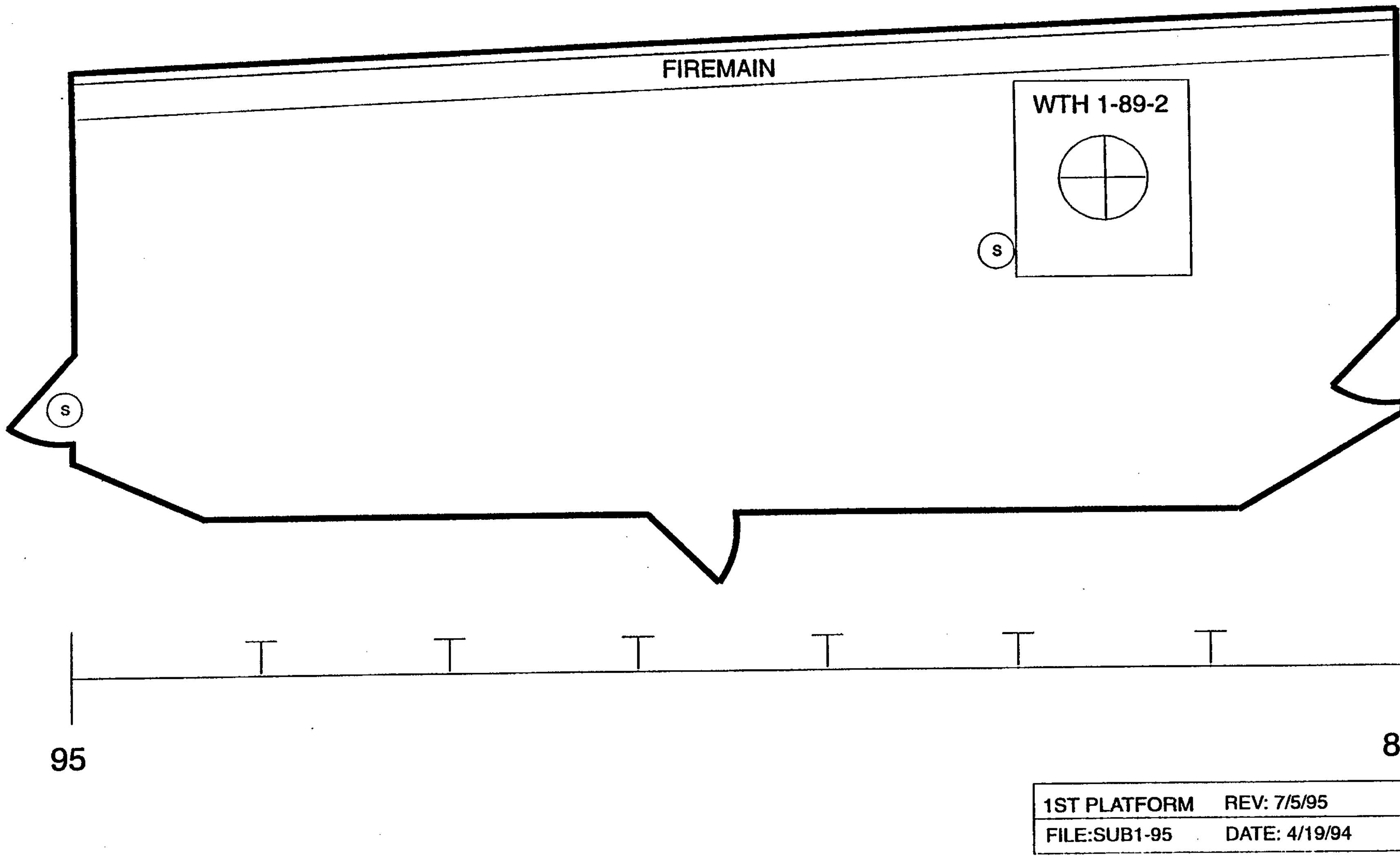

Fig. A3 – Fan room instrumentation layout

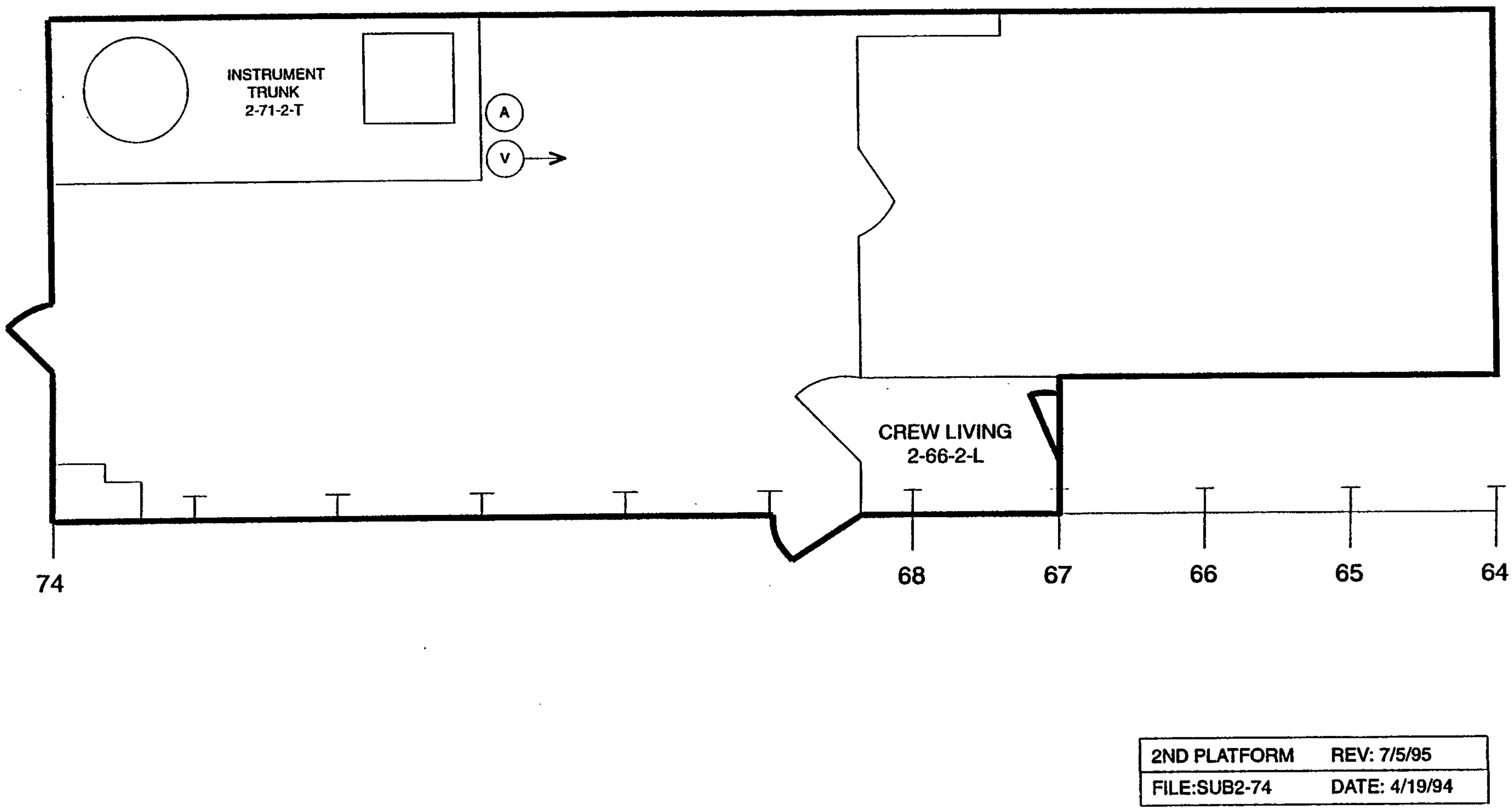

Fig. A4 – CPO living quarters instrumentation layout

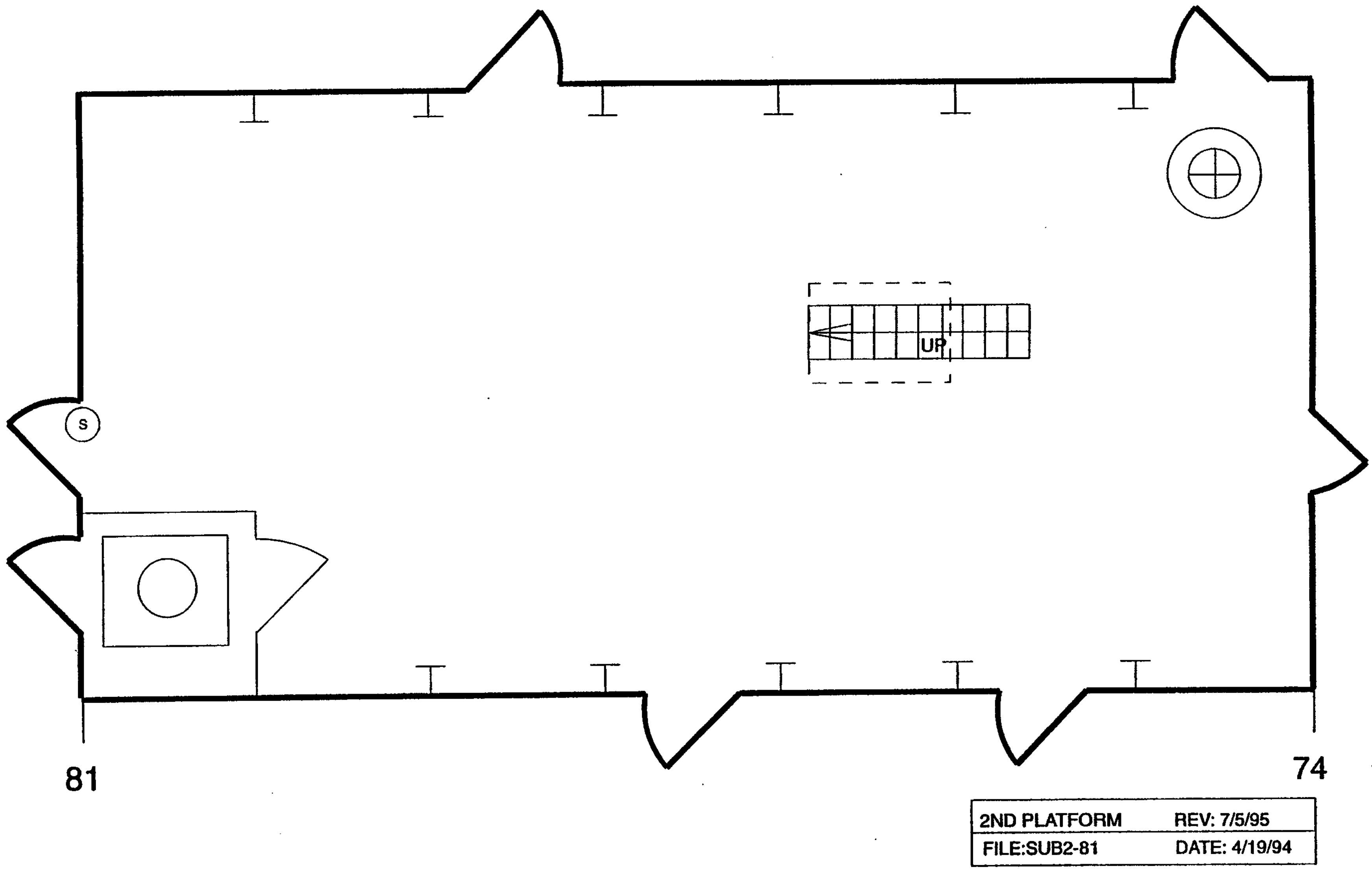

Fig. A5 – Crew living instrumentation layout

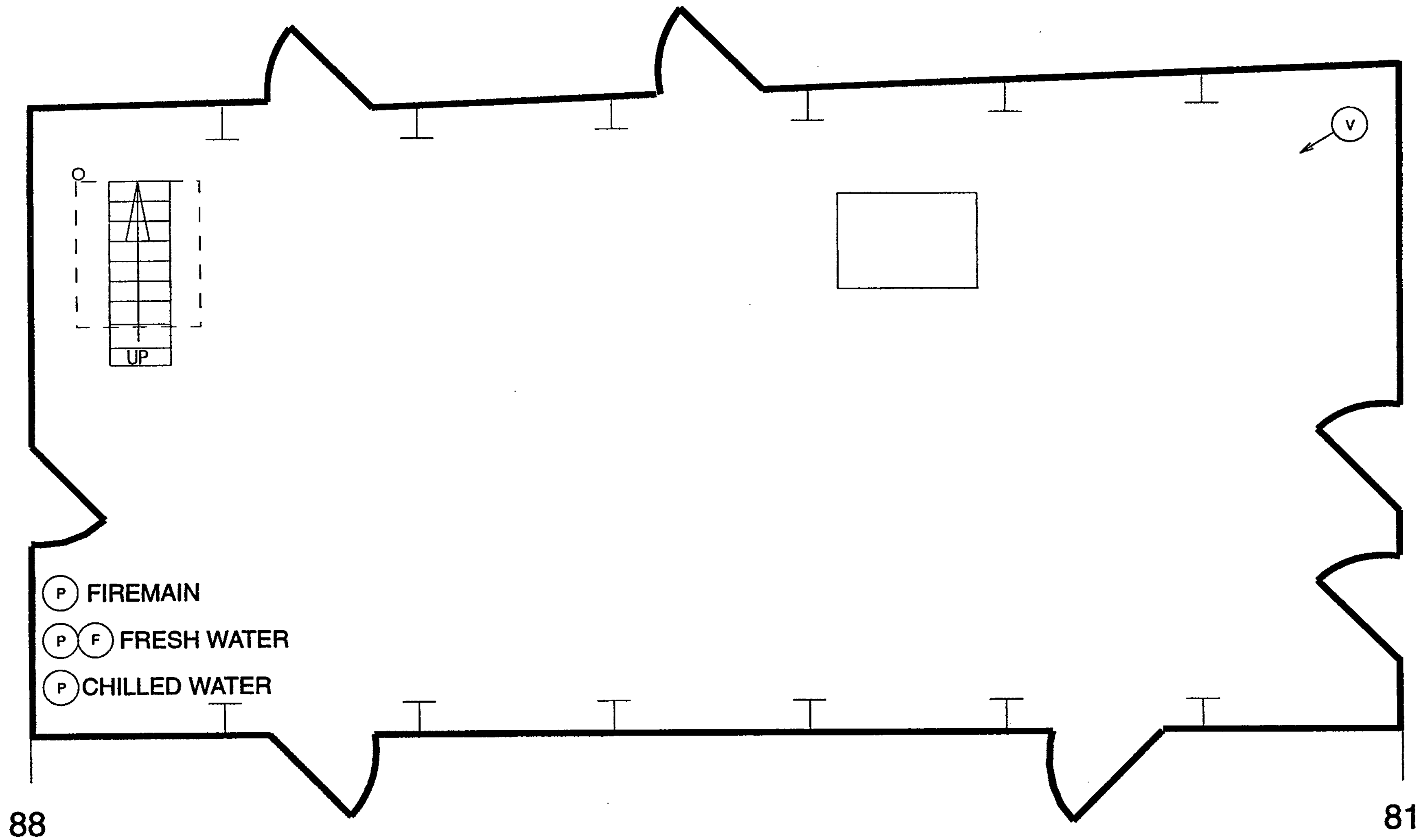

Fig. A6 – Wardroom instrumentation layout

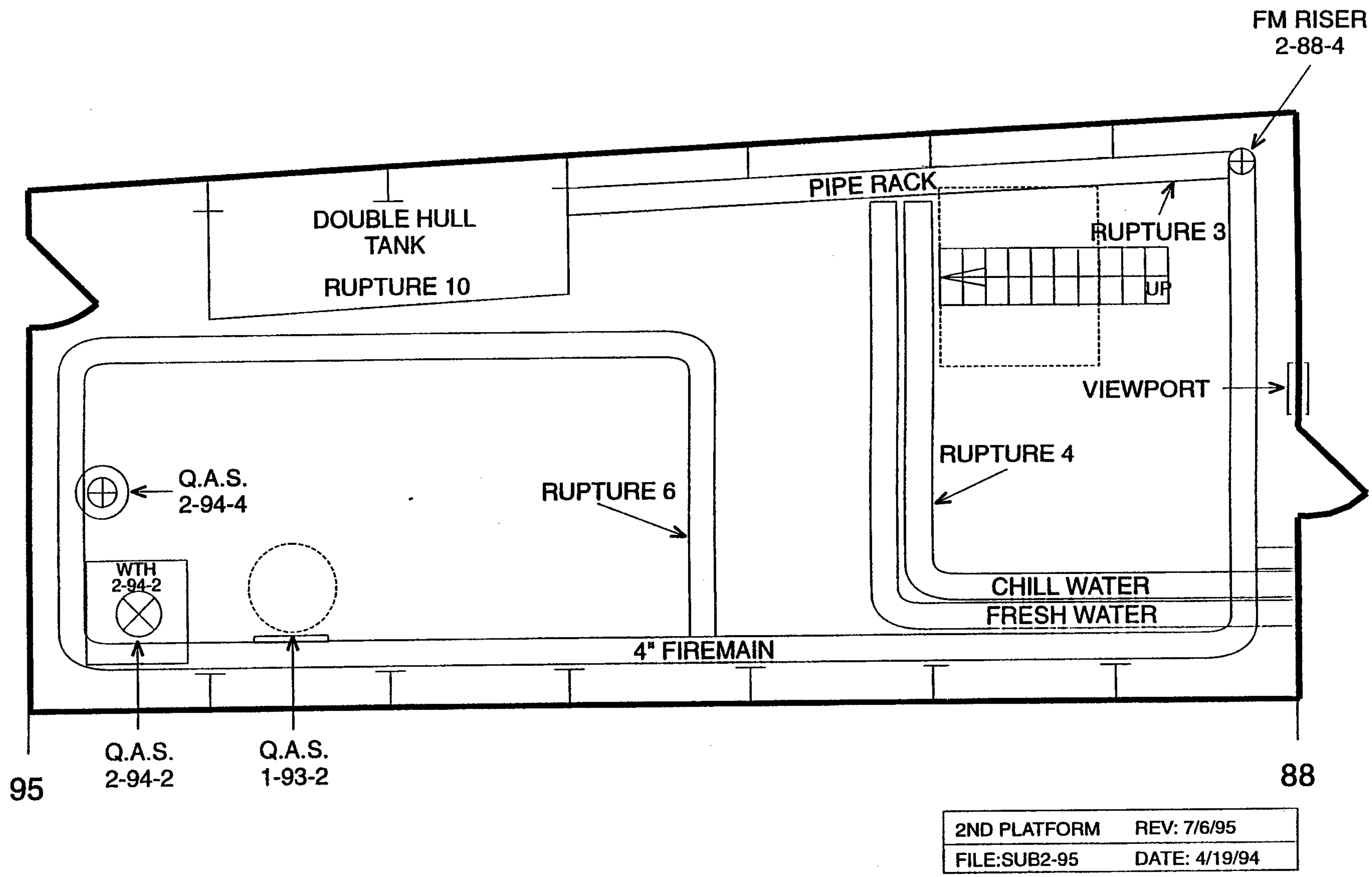

Fig. A7 – Upper wet compartment instrumentation layout

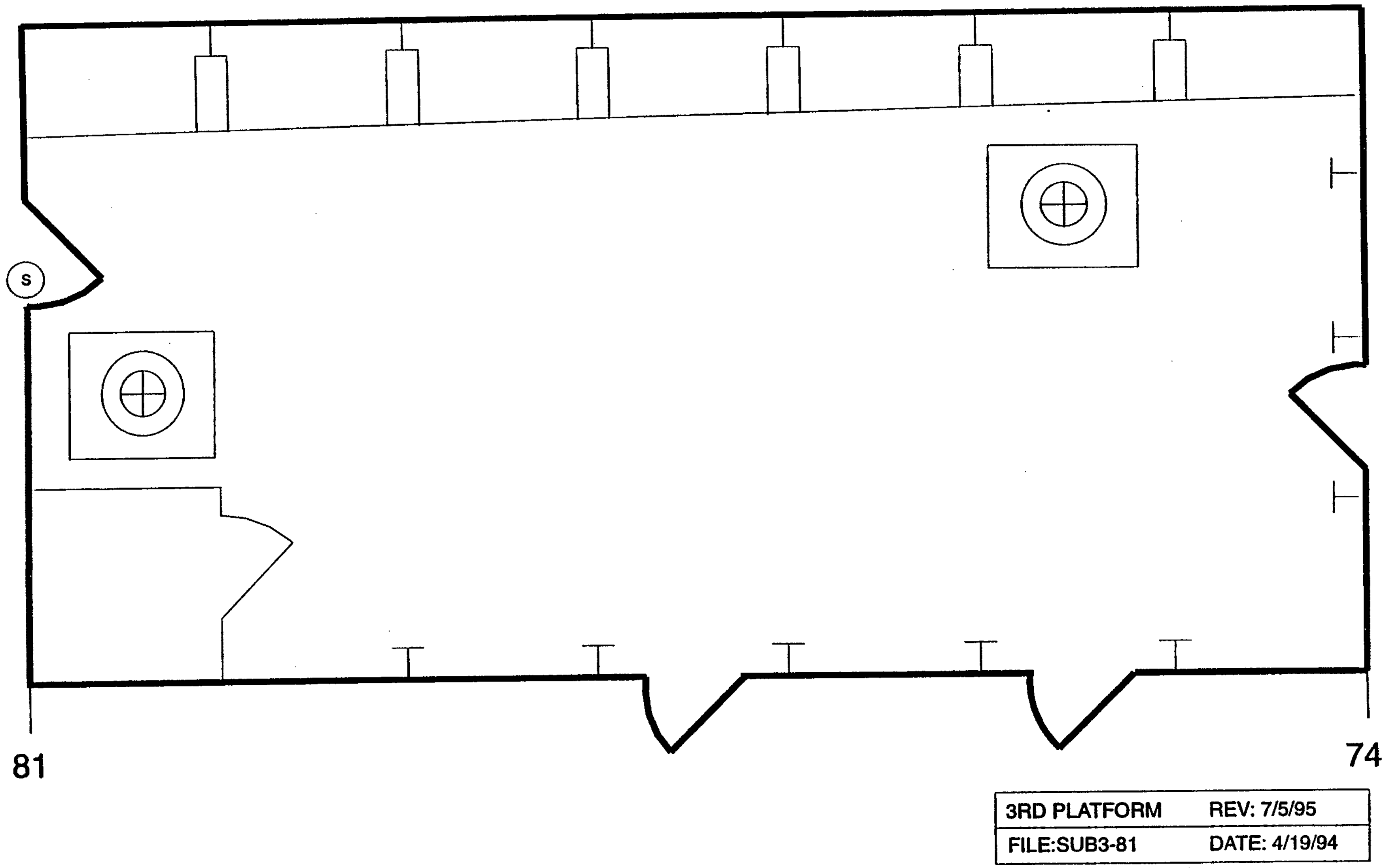

Fig. A8 – Torpedo room instrumentation layout

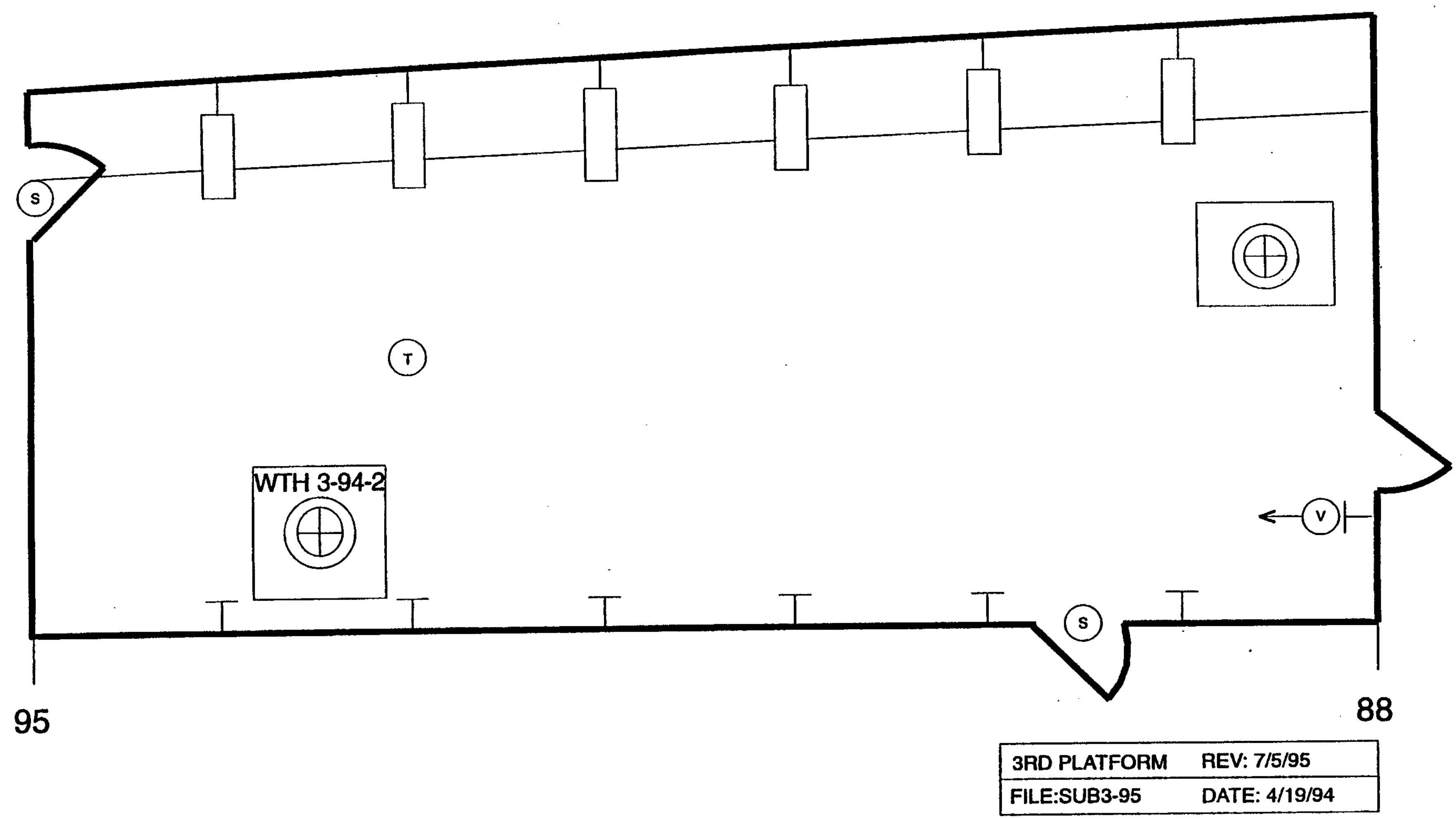

Fig. A9 – Lower wet compartment instrumentation layout

Appendix B
Instrumentation Listing

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location		REMARKS
			(x/y/z)	Frame No.	
			CONTROL ROOM (1-81-2)		
1	Microswitch	0-1	QAWTD 1-85-2		Attach to WTD frame such that; open = 0, closed = 1
2	Microswitch	0-1	QAWTD 1-88-2		Attach to WTD frame such that; open = 0, closed = 1
			FAN ROOM (1-88-2)		
3	Microswitch	0-1	QAWTH 1-89-2		Attach to WITH frame such that; open = 0, closed = 1
4	Microswitch	0-1	QAWTD 1-95-2		Attach to WTD frame such that; open = 0, closed = 1
			PASSAGEWAY (2-68-2)		
5	Video (camera)	N/A	2.5/0.0/2.0	2-77-1	Mount high on inboard bulkhead, looking aft at Repair 4 doorway.
6	Audio (microphone)	N/A	5.0/2.5/2.5	2-70-0	Mount in overhead such that it does not interfere with personnel movement.
			CREW LIVING (2-74-2)		
7	Microswitch	0-1	QAWTD 2-81-4		Attach to WTD frame such that; open = 0, closed = 1
			UPPER "WET" COMPARTMENT (2-88-2)		
8	Video (camera)	N/A	8.5/1.0/2.0	2-88-1	Mount high on forward bulkhead, toward inboard side, looking at aft-centerline. Camera must be enclosed/protected from water spray.

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location		REMARKS
			(x/y/z)	Frame No.	
9	Flow Meter	0-15 L/s (0-238 gpm)	8.6/1.0/2.0	"	Actually mounted OUTSIDE compartment on chill water supply piping. Turbine flow meter.
10	Pressure	0-1500 kPa (0-218 psi)	8.6/1.0/2.2	"	Actually mounted OUTSIDE compartment in chill water supply piping.
11	Flow Meter	0-15 L/s (0-238 gpm)	8.6/1.0/2.0	"	Actually mounted OUTSIDE compartment on firemain supply piping. Ultrasonic meter will be "strapped" to pipe.
12	Pressure	0-1500 kPa (0-218 psi)	8.6/1.0/2.2	"	Actually mounted OUTSIDE compartment in firemain supply piping.
13	Video (camera - Wide Angle Lens req'd)	N/A	5.0/0.0/2.0	2-91-1	Mount high on inboard bulkhead, looking across compartment in the "aft" direction. Camera must be enclosed/protected from water spray.
14	Thermocouple	0-100°C	0.1/3.3/2.1	2-95-2	Use EXISTING T/C string.
15	"	"	0.1/3.3/1.8	"	"
16	"	"	0.1/3.3/1.5	"	"
17	"	"	0.1/3.3/1.2	"	"
18	"	"	0.1/3.3/0.9	"	"
19	"	"	0.1/3.3/0.6	"	"
20	"	"	0.1/3.3/0.3	"	"

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location (x/y/z)	Location Frame No.	REMARKS
21	Audio (microphone)	N/A	1.0/1.5/2.5	2-94-0	Mount in overhead such that it does not interfere with personnel movement. Must be protected from water spray.
22	Video (camera - Wide Angle Lens req'd)	N/A	0.0/0.1/2.0	2-94-2	Mount high at the junction (corner) of the inboard and aft bulkheads, looking (forward) toward the center of the compartment. Camera must be enclosed/protected from water spray.
			DC SHOP (2-95-4)		
23	Video (camera)	N/A	0.0/1.5/2.0	2-99-0	Mount high on aft bulkhead, near centerline. Looking forward at QAWTD 2-95-2.
24	Audio (microphone)	N/A	2.5/1.5/2.5	2-97-0	Mount in overhead such that it does not interfere with personnel movement.
			TORPEDO ROOM (3-74-2)		
25	Microswitch	0-1	QAWTD 3-81-2		Attach to WTD frame such that; open = 0, closed = 1
			LOWER "WET" COMPARTMENT (3-88-2)		
26	Video (camera - Wide Angle Lens req'd)	N/A	8.5/1.0/2.0	3-88-1	Mount high on forward bulkhead, near centerline, looking aft along centerline of compartment. Camera must be enclosed/protected from water spray.
27	Thermocouple	0-100°C	0.3/0.2/2.1	3-94-1	Aft T/C string.
28	"	"	0.3/0.2/1.8	"	"

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location (x/y/z)	Location Frame No.	REMARKS
29	"	"	0.3/0.2/1.5	"	"
30	"	"	0.3/0.2/1.2	"	"
31	"	"	0.3/0.2/0.9	"	"
32	"	"	0.3/0.2/0.6	"	"
33	"	"	0.3/0.2/0.3	"	"
34	Microswitch	0-1	QAWTD 3-89-2		Attach to WTD frame such that; open = 0, closed = 1
35	Microswitch	0-1	QAWTD 3-95-2		Attach to WTD frame such that; open = 0, closed = 1
STERN GATE MACHINERY ROOM (3-100-2)					
36	Microswitch	0-1	QAWTD 3-101-2		Attach to WTD frame such that; open = 0, closed = 1
PORT WING WALL - WEATHER DECK					
37	Flow Meter	0-15 L/s (0-238 gpm)	N/A	1-80-2	Install ("strap") Ultrasonic meter to firemain supply pipe, at main deck level. Piping located inside "combat systems" (sub) space.
38	Pressure	0-1500 kPa (0-218 psi)	"	"	Install in firemain supply piping at main deck level. Locate adjacent to item #38.

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location		REMARKS
			(x/y/z)	Frame No.	
39	Video (camera)	N/A	N/A	1-58-2	Install such that forward access to "combat systems" (sub) space (QAWTD 1-75-2) is in view. Camera must be installed such that it does not interfere with normal personnel "traffic". Camera must be enclosed/protected from weather (or temporary/daily mount).
40	"	"	"	1-110-2	Install such that aft access to "fan room" (sub) (QAWTD 1-95-2) is in view. Camera must be installed such that it does not interfere with normal personnel "traffic". Camera must be enclosed/protected from weather (or temporary/daily mount).
STARBOARD WING WALL - WEATHER DECK					
41	Flow Meter	0-15 L/s (0-238 gpm)	N/A	1-80-1	Install ("strap") Ultrasonic meter to firemain supply pipe, at main deck level.
42	Pressure	0-1500 kPa (0-218 psi)	"	"	Install in firemain supply piping at main deck level. Locate adjacent to item #41.
43	Video (camera)	N/A	N/A	1-58-1	Install on inboard side of wing wall, looking aft and down into well deck area, focused in the vicinity of the access to the lower wet compartment (QAWTD 3-89-1). Camera must be enclosed/protected from weather (or temporary/daily mount).
44	Video (camera - Wide Angle Lens req'd)	"	"	1-101-1	Install on inboard side of wing wall, looking slightly aft and down into well deck, focused in the vicinity of the "double hull" mock-up. Camera must be enclosed/protected from weather (or temporary/daily mount).

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location		REMARKS
			(x/y/z)	Frame No.	
45	Video (camera)	"	"	Mast	Install on mast, looking aft into well deck area.
46	Flow meter	0-15 L/s (0-238 gpm)	N/A	3-90-0	Mounted on pipe rig.
47	Pressure	0-1500 kPa (0-218 psi)	N/A	3-90-0	Mounted on pipe rig.